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VOLUME LIII NUMBER 6

THE JOURNAL of GEOLOGY

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ROLLIN T. CHAMBERLIN

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J HARLEN BRETZ, Geomorphology
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NOVEMBER 1945

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November 1945

THE MOON'S LACK OF FOLDED RANGES

ROLLIN T. CHAMBERLIN
University of Chicago

ABSTRACT

The moon shows little evidence of folded mountain ranges. Faulting (especially in radial and concentric patterns) has been prevalent; and one area of aligned ridges, which extends several hundred miles from the Mare Imbrium, across the elevated environs of the Mare Serenitatis and the Mare Tranquilitatis, and is older than the flattish maria surfaces, shows some resemblance to our faulted Basin Ranges. But why are the long arcuate folded ranges, so characteristic of the earth, lacking on the moon?

What have been the notably different conditions on the moon and the earth which may have been responsible for their dissimilar diastrophic histories? Four differences come readily to mind: (1) The moon has neither atmosphere nor hydrosphere. (2) The moon has only 1/81 of the earth's mass, and its surface gravity is only about one-sixth as great. (3) Its average density is only 3.34, against 5.52 for the earth. (4) Its period of rotation is a little over 27 days, compared with the earth's daily rotation.

Some of the possible consequences of these differences are discussed briefly to indicate lines for further investigation.

INTRODUCTION

The most striking features on the face of the moon are the multitudinous craters, large and small, which scar its surface. These rimmed pits are generally thought to represent the moon's volcanic activities since very early in its history. An alternative hypothesis attributes them to explosions from the impact of large meteoritic masses. However formed, it is agreed that, in the absence of an atmosphere and hydrosphere, they escape the rapidly destructive gradational processes prevalent on the earth and should persist for great lengths of time, except as affected by later volcanism, meteoritic impacts, or lunar diastrophism. Much of the lunar facial expression is thus presumably very old.

But if the pits record topographic developments since remote times, where are the folded mountain ranges so characteristic of earth history? If formed, they likewise should be very long-lived. Photographs of the moon show surprisingly little evidence of folding. Some differences, of course, are to be anticipated. A corrugated lunar surface would remain uneroded; and we should not expect to see such close folding as in a deeply dissected terrestrial mountain system, where the folds commonly become sharper, smaller, and more numerous downward. Yet, if comparable mountain systems had developed on the moon, we should at least expect to see long belts of prominent, closely spaced wrinkles, with paralleling fault scarps; for rocks both bend and break, even when not subjected to confining pressures due to deep burial, as warped tombstones show. But on the moon we look in vain for great arcuate

strips of strong, paralleling corrugations, so familiar from our Appalachians, Juras, and many other terrestrial mountain systems.

LUNAR FAULTING

Faulting has occurred abundantly on the moon, although N. S. Shaler,[1] in spite of many years of study of photographs and by telescope, seems to have failed to recognize much of it as such. Many steep declivities in common alignment, however, can hardly be other than fault scarps and are now so regarded. Most characteristically these lunar faults fall into two categories: (1) a system radiating outward from a center of disturbance (like the Mare Imbrium); and (2) faults concentric with crater walls or with the margin of a mare (Fig. 1). Both these types show some resemblance to those developed on the earth by upswelling and collapse of domical uplifts. The first fault pattern may call to mind the array of dikes diverging from the Spanish Peaks intrusive mass in Colorado.[2] Upward pressure from underlying magma domes the surface, stretching and fracturing the rocks along radiating lines, which may become dikes or faults.[3] Radial fractures may also form because of horizontal pressure outward from a volcanic neck or a stock.[4] These may be added to those developed by doming. Faults of the second type, concentric with a lunar crater rim, step down its inner slope in successive blocks, somewhat as in the Kilauea caldera. Sinking of the caldera floor, or floor of a mare, by failure of underlying support, is the apparent reason for this succession of marginal normal faults. Common, also, is what looks like graben sinking between faults.

Recently a very thorough study and interpretation of the facial features of the moon, particularly as revealed in the Mare Imbrium region, has been presented by J. E. Spurr.[5] The Mare Imbrium, or Imbrian plain, is encircled by an elevated rim, greatly roughened by faulting, portions of which have been designated the "Apennines," "Carpathians," and "Alps." Along the inner side of these "ranges," as along other sections of the nearly circular rim, long fault scarps facing the mare show how that area has dropped from its surroundings in caldera fashion. But even more striking on Spurr's sketch map of the Imbrian fault system[6] are the very numerous transverse faults cutting the rim normal to the concentric downfaulting. Some of these are more than 100 miles in length. Converging, they point toward the middle of the mare; but they terminate abruptly at the mare border except in front of a portion of the Apennines, where lines of low scarps, peeping above the Imbrian plain, extend major transverse faults of the rim far out into the mare.

Subsequent to the faulting, according to Spurr, the sunken mare floor has been covered by vast floods of lava which obliterated its earlier relief and gave most

[1] "A Comparison of the Features of the Earth and the Moon," *Smithsonian Contributions to Knowledge*, Vol. XXXIV (1907), pp. 1–131.

[2] "Spanish Peaks Quadrangle," *U.S. Geol. Surv. Folio 71* (1901).

[3] T. A. Link (*Jour. Geol.*, Vol. XXXV [1927], pp. 327–39) has produced both ringlike and radial fractures by forcing a cylinder of plaster of Paris (and likewise liquid materials) upward into artificial strata. His concentric fractures, however, illustrate the formation of cone sheets better than the normal faulting around a sinking caldera.

[4] Willard H. Parsons, "Volcanic Centers of the Sunlight Area, Park County, Wyoming," *Jour. Geol.*, Vol. XLVII (1939), pp. 1–26.

[5] *Geology Applied to Selenology* (Lancaster, Pa.: Science Press Printing Co., 1944).

[6] *Ibid.*, p. 42, Fig. 11.

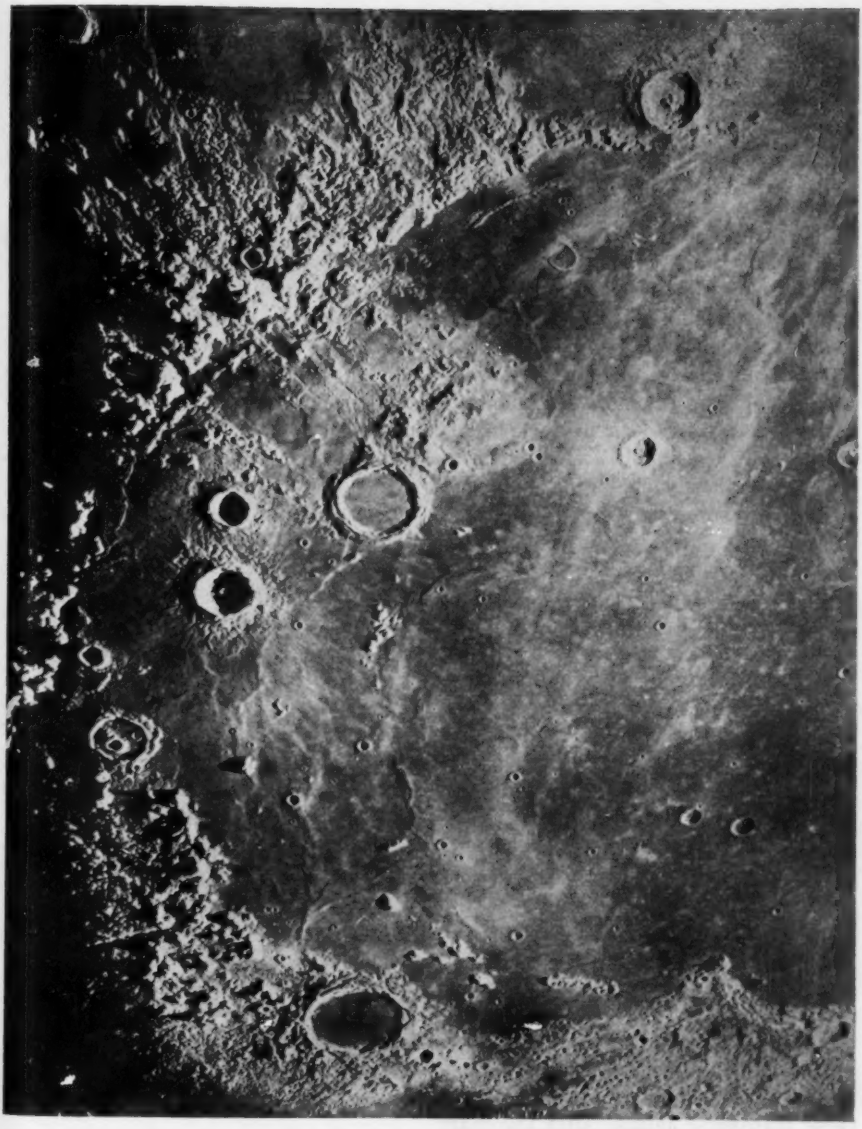

FIG. 1.—A portion of the Mare Imbrium and its elevated rim. The northwest section of the rim is termed the "Apennines." Faults scarps, both transverse to the rim (radial to the mare) and concentric with it, are evident. Photographed September 15, 1919, at the Mount Wilson Observatory, California.

of the mare its relatively flat surface.[7] But opposite the Apennines, it would seem that a patch of the older faulted surface remained too high to be buried completely, for here partially submerged scarps are still visible (see Fig. 1). Scarps concentric with the rim are likewise discernible.

The Mare Imbrium is over 700 miles in greatest diameter. How much of the faulting radiating from it may be attributed reasonably to tension during the postulated updoming and how much is better explained by horizontal outward shove from the mare area is uncertain. Horizontal movement along many of the transverse faults, subsequent to the concentric faulting, has been inferred by Spurr, whose diagrammatic sketches show much offsetting of the Apennine and Carpathian mountain fronts.[8] On the latter front, however, the younger mare surface reaches quite a few miles into the range between certain pairs of transverse faults, suggesting that these "bays" of the mare, or re-entrants in the range, occur where some fault blocks have dropped lower than their neighbors. In most of these cases the "sea" has penetrated considerably farther along one fault line than along the other, as if tilting of the included fault block had brought that side lower. Moreover, the "shoreline" appears too much and too variously curved to be explained solely as a basin border, offset by horizontal displacement on the faults (see Fig. 2). Differential vertical movement can readily explain most of the offsetting. How much horizontal slip may have occurred along these transverse faults, after the mare area began to sink and before the flooding, is consequently not readily determinable. But on the Apennine front, evidence of important strike slip on the radiating faults is more convincing. Compared, however, with the magnitude of the Imbrian mare, this has been rather moderate in amount.

While the pattern of faults diverging from the Imbrian mare is such that a genetic relationship seems likely, it is, nevertheless, surprising how far nearly parallel fault scarps extend northwestward[9] from the mare. The scarps are very discontinuous; but they have a common alignment for several hundred miles, producing a crude structural grain revealed by light and shadow (Fig. 3). They continue prominently across the elevated environs of the Mare Serenitatis and the near-by Mare Tranquilitatis.[10] In fact, these two maria have obliterated this older faulted surface over large areas and have done so without imparting any very noticeable fault pattern of their own. Whatever doming and collapse occurred in the development of these maria has left much less apparent effect on their surroundings than in the case of the greater Imbrian mare.

Perhaps, therefore, too much of this lunar faulting has been credited to the maria as by-products in their evolution. It may be noted that the most strongly developed radial faulting around the Imbrian mare is in this continuous tract of northwest-trending scarps, which show little genetic relationship to the Serenitatis and Tranquilitatis maria. Possibly this structural grain is the ex-

[7] Shaler, however, although favoring the volcanic hypothesis for the craters, considered extensive melting of the lunar surface by the impact of giant bolides the most acceptable explanation of the maria (pp. 15–21 of ftn. 1).

[8] Figs. 11 and 12 of ftn. 5.

[9] Photographs oriented with image inverted as seen through an inverting telescope. True orientation of the scarp trend would be southwestward as seen with naked eye or through field glasses, with north at top in northern hemisphere and west to the right.

[10] Pls. XVIII and XXII of ftn. 1.

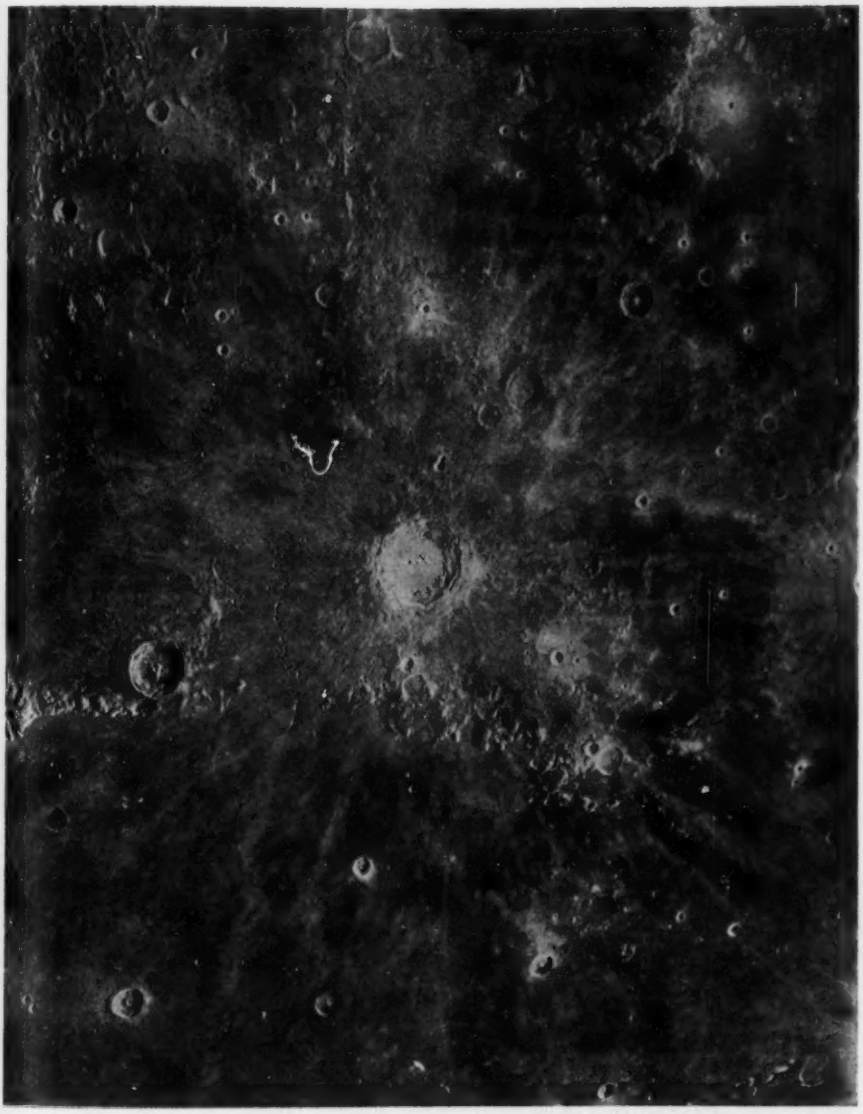

FIG. 2.—Region of Copernicus (central large crater). This photograph overlaps Fig. 1 and extends that area northeastward. The Imbrian mare occupies its lower third. The portion of the Imbrian rim just below Copernicus is termed the "Carpathian Range." Note the fault ridges transverse to this rim which radiate from the mare; also, the small "bays" of the mare which penetrate the rim. Photographed September 15, 1919, at the Mount Wilson Observatory, California.

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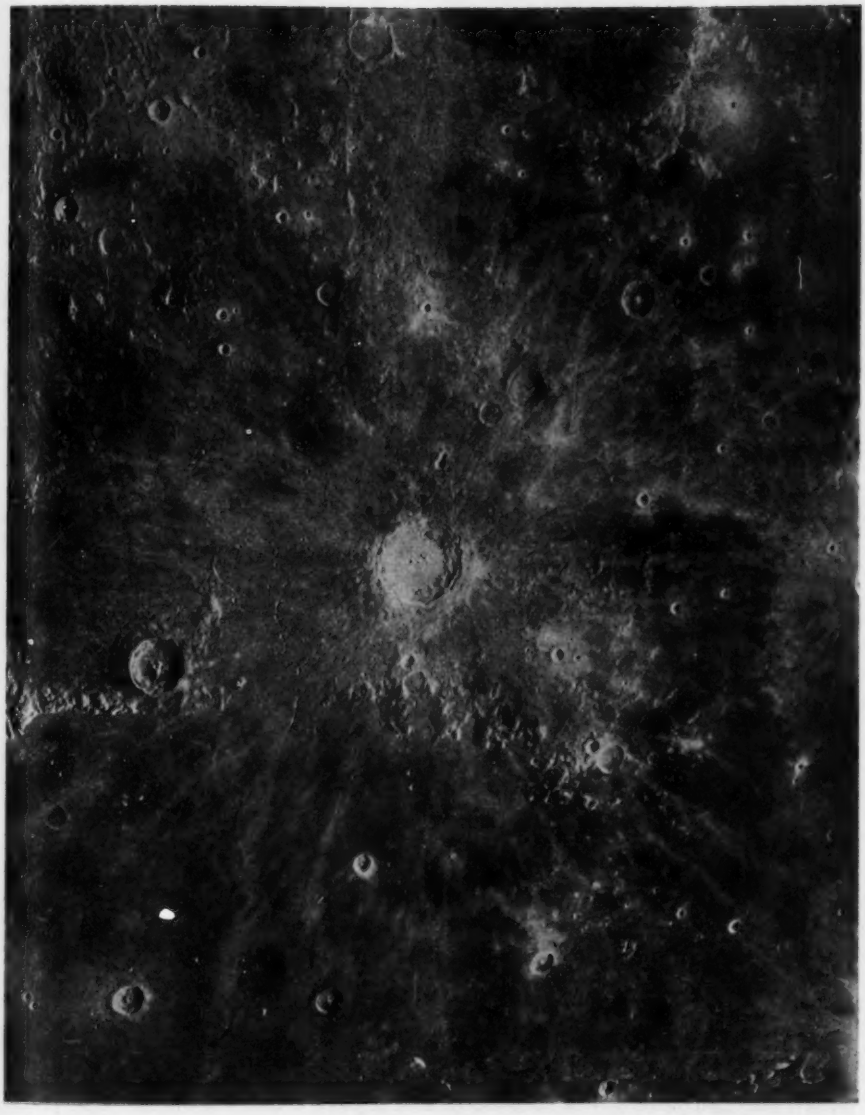

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FIG. 3.—Mare Serenitatis (*lower center*) and Mare Tranquilitatis (*upper left*) with a bit of the Mare Imbrium in lower right corner. Note the northwest-southeast alignment of short, discontinuous ridges (presumably faulted) in the older uplands above the maria surfaces. Prominent serpentine wrinkle ridge runs north and south across the smooth Mare Serenitatis. Enlarged from a photograph made with the 40-inch refractor, Yerkes Observatory, Williams Bay, Wisconsin. Kindness of Dr. Otto Struve.

pression of a larger regional diastrophism (not altogether unlike the Basin Range faulting in the western United States), to which the Mare Imbrium has added its own fault system. Some contraction of the moon should be expected on any hypothesis of its origin, and the parallel faulting throughout this considerable tract may have resulted in part from such contraction. In any case, this faulting is older than the relatively smooth surfaces of the maria. Our only evidences of lunar diastrophism since the maria floors were formed are a few isolated faults and feeble wrinkles on their surfaces.

MARIA WRINKLE RIDGES

Some gentle wrinkling of the lunar surface is revealed by differences in illumination showing low, narrow upfolds, several of which are a hundred miles or more in length, whereas others are quite short. The greatest elevation assigned to any one of them, however, is less than 2,000 feet.[11] They are features of the maria floors and, although not numerous, are most prominent on the Mare Imbrium, the Mare Serenitatis, and the Mare Nectaris. Shaler states:

> So far as I have been able to ascertain, well developed continuous ridges are limited altogether to the maria and practically so to the larger fields of this nature; in the smaller maria they are much less distinct, though there are instances of slight undulations which may belong in the same category of structures.[11]

The most striking wrinkle ridge, which Shaler says "more distinctly resembles a terrestrial mountain chain than any other elevation on the moon," has a serpentine course across the Mare Serenitatis in a general north-and-south direction.[12] In some parts of its course (see Fig. 3) it is a single continuous ridge; in several places this gives way to two or more weaker, overlapping ridges; and toward each end of the chain the single ridge forks in widely diverging branches. Its over-all curvature is concave toward the middle of the mare. The echelon arrangement of individual ridges in several parts of this chain of arcs recalls strikingly the experiments of S. Tokuda,[13] who obtained similar fold patterns by placing a thin sheet of plastic paper coated with a thin layer of rice paste on a glass plate and then pushing the paper forward with his finger.

Spurr's analytical chart No. 1 of the Mare Imbrium[14] shows three main lines of wrinkling and various tiny ones with accordant orientation. Two lines curve around the western side of the mare (true orientation), while the other, at least 200 miles in length, bends around it on the east. Spurr says:

> This indicates that the mare flood, creeping up from the central part of the Mare, upon its "shores," was in its later stages plastic enough for the surface to be warped into wrinkles by the resistance of the bottom over which it advanced.

Certainly, no general lunar diastrophism is suggested by these few wrinklings of the maria floors in a late stage of their development.

How old the maria floors are, we do not know. But it is clear that, since their flattish surfaces were acquired, relatively little diastrophism has occurred on the moon. Meanwhile the earth has been producing great mountain systems from early pre-Cambrian times practically to the present.

[11] P. 36 of ftn. 1.

[12] *Ibid.*, p. 116, Pl. XVIII.

[13] "On the Echelon Structure of the Japanese Archipelagoes," *Japanese Jour. Geol. and Geog.*, Vol. V, Nos. 1–2 (1926–27), pp. 41–76.

[14] P. 7, Fig. 2, of ftn. 5.

DIFFERENT CONDITIONS ON MOON AND EARTH

The writer has long wondered at the lack of strong folding on the moon and has thought that its absence there should suggest leads toward a better understanding of terrestrial deformation. Spurr's recent application of geology to selenology has awakened dormant thoughts on the application of selenology to geology. Lunar conditions are different from terrestrial conditions, and in those differences one should seek the reasons why diastrophism has operated so dissimilarly on the two companion bodies. Presumably, therefore, the added vision from this new point of view may be brought to bear discriminatingly on the basic causes of earth deformation.

We ask ourselves, accordingly: What have been the notably different conditions on the moon and earth which may have been responsible for their dissimilar diastrophic histories? Four differences come readily to mind: (1) The moon has neither atmosphere nor hydrosphere. (2) The moon has only 1/81 of the mass of the earth, and its surface gravity is only about one-sixth as great. (3) Its average density is only 3.34, against 5.52 for the earth. (4) Presenting always the same face to the earth, it rotates but once during its $27\frac{1}{3}$-day circuit around the earth.

LACK OF ATMOSPHERE AND HYDROSPHERE

The ceaseless erosion of the earth's land surface by wind and water has no counterpart on the moon. These agents transfer no rock material from higher portions of the lunasphere to its lower surfaces, and no sedimentary rock formations develop. On the earth, folding into mountain ranges occurs principally where geosynclinal accumulation of weak sediments has reached many thousands of feet in thickness. Such accumulations are missing on the moon. In class discussions it has often sufficed to remark: "No geosynclines, no mountain-folding on the moon." But is this sweeping generalization really a complete answer? There can be little doubt that geosynclines have played an extremely important part in the great orogenies on our globe. They have been mobile belts of long duration; in general, they are favorably located with respect to growing earth stresses; weak sediments there extend to exceptional depths; and stratified sedimentary rocks fold more readily than nonstratified rocks by adjustments along bedding planes. That geosynclines should be the belts to yield, when tangential compressive stresses reach sufficient intensity, is natural. Strong folding takes place there more readily than elsewhere, and by this crustal shortening the stress conditions are relieved.

But while geosynclines locate the orogenies and unquestionably facilitate them, is it certain that their absence precludes notable folding? If we assume the same sources of tangential stress (whatever they are), would the earth's crust, unweakened by geosynclines, be sufficiently resistant not to shorten very considerably by buckling and thrust faulting? Trial computations based on assumed quantitative values might sharpen the focus on this question but probably would not resolve it, owing to the uncertain factors. However, it would not seem unreasonable to expect considerable crustal shortening by orogenic deformation without geosynclines, albeit less than with them and less concentrated in distinct belts.

Igneous rocks do not flex so readily as sedimentary strata, particularly near the earth's surface; but successive lava flows and pyroclastics do provide surfaces of weakness along which adjust-

ment can take place in bending, and even massive granite changes its shape without dependence on large-scale fracturing. In some of the great folds in the Rocky Mountains the smooth upper surface of the pre-Cambrian granite has a curvature identical with that of the basal Cambrian layer in contact with it. We say that the vertical or overturned Cambrian beds have been folded; but whether we call the bending of the granite-quartzite contact "folding" or not, the fact remains that the granite has deformed to the same configuration as the quartzite. Where the sedimentary formations have been stripped from the granite and other pre-Cambrian rocks, the latter now constitute the mountain ranges towering above the plains and near-by basins. Faults on an important scale may, or may not, be present.

Moon materials are less conducive to folding than those of the outer earth crust; but an orogeny by the requisite combination of flexing and faulting should be possible, provided the rocks are sufficiently stressed. That such has not occurred indicates insufficient tangential compressive forces. Absence of gradational processes eliminates one source of such forces. There is neither unloading of some areas by erosion nor loading of other areas by deposition of sediments.[15] Consequently, there would be no lateral crowding by a heavy subsiding segment against a lighter segment to operate, trigger-like, in setting off orogenic deformation by the general tangential forces in a shrinking globe. Likewise, much less isostatic adjustment would be brought into play. Also, without fluvial or eolian transfer of enormous masses of material from some portions of the moon's surface to other distant portions (as on the earth), there would be no shifting thereby of the moon's axis of rotation, with possible consequent distortion of the rotating globe. This last difference in diastrophic potentialities will be considered later.

[15] Ignoring very local talus.

LESSER MASS, GRAVITY, AND DENSITY

Although it is now rather widely recognized that the earth's crust has suffered far too much folding to be explained by shrinkage of the globe due to cooling alone, such contraction needs to be considered. An earth and a moon cooling from a postulated liquid condition to their present states should follow somewhat comparable courses. While the smaller moon would cool faster than the more massive earth and the ratios between the forces developed and the strength of materials would not be the same, the two bodies should undergo somewhat proportionate crustal shortening, with deformation likely to differ more in degree than in kind. But many ramifying factors would complicate any quantitative assay of the probable differences.

The small size of the moon may lead one quickly to the question: Assuming a completely molten moon, could it have undergone most of its cooling and contraction so early in its career that crustal shortening practically ceased before the maria were developed? They show little deformation; yet if we accept the volcanic theory for most of the lunar craters and maria, heat was still causing very extensive volcanism. Meanwhile the earth has been in orogenic throes, with little evidence of waning intensity, right to the present time. But we need not go further; cooling of the earth is no longer considered the principal cause of its crustal folding. To bring an estimate of the earth's crustal shortening into any sort of harmony with the total amount

obtainable under the thermal-contraction theory, it is necessary to ignore all the great pre-Cambrian folding, which is known to be intricate over vast surface areas and presumably also extends beneath millions of square miles of younger formations.[16] Also, mountain-building was very extensive in Cenozoic times, and we have no assurance that the earth was then losing much more heat than was being produced within it by radioactive processes.

Internal convection in a liquid state or even in solid material has, for several decades, been a postulated causal mechanism for orogenic deformation. In essentially solid globes, proximity of internal temperatures to the liquefaction point (represented by the temperature–pressure-fusion curve) should favor possible convective movements. Perhaps such a condition more nearly obtains in the earth than in the smaller satellite. But involved, also, would be liberation of new heat and unstable gravity relations. In the case of the moon, its strange ellipticity indicates that there has been no internal convection adequate to bring the satellite's shape into equilibrium with the forces operating during its later history.

The moon's weaker gravitation should affect deformation in several ways. Upbowing by tangential compression is opposed by less gravity on the moon, favoring the rise of anticlines and overthrust faulting. Fault blocks override with less friction. Cubic compression at a given depth below the surface strengthens the rocks less than at the same depth on the earth, though heat and other variables complicate the problem, which, indeed, is not a simple one. Larger blocks can remain out of isostatic equilibrium on the moon, and isostatic adjustment might be accomplished somewhat differently on the two globes. These and related differences are possible factors in comparative lunar and terrestrial diastrophism; but, obviously, they are not of the right sort to have been the dominating ones.

But gravity may operate more importantly in compaction and global shrinkage. One of the striking differences between the two bodies is a density of 5.52 for the earth and only 3.34 for the moon. The rocks near their surfaces should not differ radically in inherent specific gravity, but there may be considerable differences in porosity. Lavas should become more vesicular and pumiceous under low lunar pressures; and meteoric waters would not fill the cavities with mineral matter, although magmatic waters might. Accumulations of volcanic ejectamenta could retain high porosity to considerable depths. But such would be offset by porous terrestrial sediments and the low density of our oceans.

The excess of 5.52 over 3.34 comes chiefly from heavier material deep in the earth. Regardless of a postulated greater proportion of iron in the earth than in the moon, much of the earth's higher density results from the greater compression of the larger body. E. D. Williamson and L. H. Adams'[17] have given curves for the change of density due to compression alone from the earth's surface halfway to its center. For two initial densities, 3.0 and 3.5 (corresponding to average gabbro and dense peridotite), their curves rise to 4.9 and 5.5, respectively, at a depth of 3,200 km. They indicate very considerable compression, although "it is clearly evident that the density is not increasing fast enough to make the

[16] See *Jour. Geol.*, Vol. XXXII (1924), p. 550.

[17] "Density Distribution in the Earth," *Jour. Wash. Acad. Sci.*, Vol. XIII (1923), p. 419, Fig. 2

mean density of the earth equal to 5.5"; to obtain this high figure, we must fall back on the only reasonable alternative, namely, that the deep interior is of intrinsically heavier material, probably iron.[18] In any case, it is clear that in self-compression lies one of the notable differences between earth and moon.

Many years ago, T. C. Chamberlin urged the importance of rearrangements in the interior of the earth in favor of greater density as a means of earth contraction and cause of megadiastrophism. This was a contraction not dependent on earth-cooling, whose inadequacy to produce the geologic results was becoming apparent. Self-compression of the globe involves far more contraction than is possible from cooling; but it must, of course, have operated through the span of geologic time if it is to meet the requirements of the earth's diastrophic history. Simple mechanical compression would not be so protracted a process; but appeal was made to subsidiary processes such as recrystallization, or neocrystallization, through slow molecular transfer, forming denser combinations of smaller volume under enormous pressures and varying thermal conditions. Conceivably such a process might be very slow and intermittent in operation.

A. N. Winchell[19] has shown that, in regions of extensive and repeated intrusions, several effective factors operate, through selective fusion and solidification, to segregate the lighter, more acidic constituents of the lithosphere above and the heavier, more basic constituents below. If there were no shell-like arrangement initially, such would develop. Geszti has investigated the problem of gravimetric differentiation at greater depths. Beno Gutenberg epitomizes some of his results in the following words:

> As, in the deeper parts of the earth, gravity decreases with depth reaching zero in the center, all processes that are controlled by gravity must decrease in speed toward the center of the earth. Relatively small accumulations of materials that are heavier than their neighborhood will not sink toward the center of the earth. Only after larger masses of heavier materials have accumulated may extended mass movements occur, which will produce, in turn, great disturbances at the surface. Geszti correlates such revolutions in the earth with the geological epochs in which large changes have occurred.[20]

Much metallic iron is postulated in the central portion of the earth, but the low density of the moon will not allow so much heavy iron in its constitution. Because of this difference and because of the feebler lunar gravitation, the moon should not have the potentialities of the earth for internal rearrangement. Other factors may enter into the problem. P. W. Bridgman's researches[21] on the effects of high pressures have yielded some surprising results, and we cannot dismiss the likelihood of more surprises in store for us could the conditions deep in the earth be studied experimentally. Polymorphic transitions are, at least, suggestive of one line of possibilities. Changes of state and convection movements from radioactive heat have been variously considered in the problem of earth deformation.

SLOWER ROTATION

The moon rotates but once while the earth spins around twenty-seven

[18] *Ibid.*, p. 420.

[19] "Are There Granitic and Basaltic Shells in the Earth?" *Science*, Vol. LXXIX (1934), pp. 32–33.

[20] *Physics of the Earth*, Vol. VII: *Internal Constitution of the Earth* (New York: McGraw-Hill Book Co., 1939), p. 183.

[21] "Shearing Phenomena at High Pressure of Possible Importance for Geology," *Jour. Geol.*, Vol. XLIV (1936), pp. 653–69; "Polymorphic Transitions and Geological Phenomena," *Amer. Jour. Sci.*, Vol. CCXLIII-A (1945), pp. 90–97.

times. This is one of the striking differences between the two bodies. If enough of the earth's great rotational force should become available from time to time for tangential orogenic compression, herein might lie a reason for abundant folded mountain ranges on the earth and their scarcity on the moon. The lunar case being negative, does the earth offer any encouragement?

Changes in the speed of earth rotation have often been considered but have not proved very helpful. Shifting poles has been such a convenient way of explaining past climates and solving other geologic difficulties that possible forces to produce such shiftings have received considerable mathematical attention. Sir George Darwin[22] considered changes in the shape of the globe by erosion, deposition, and especially elevation and subsidence of large areas. He estimated that, if 1/200 of the earth's surface (centered in latitude 45°) be elevated 10,000 feet (effective elevation), the pole of rotation will be deflected $11\frac{1}{8}'$; if 1/20, $1^\circ\ 46\frac{1}{2}'$; if 1/10, $3^\circ\ 17'$. In each case an equal area is supposed to fall simultaneously. Darwin's figures apply to an unyielding earth; a yielding earth would require greater displacement of matter to effect the same displacement of the axis of rotation; but both Darwin and Schiaparelli fell into error in handling the case of a mobile earth.[23]

Gutenberg gives a concise treatment of the many forces connected with the rotation of the earth that have been investigated.[24] He offers little encouragement for the hope that any of them will be found important in mountain-making. At the same time, he does state:

> Larger strains are found if we suppose the existence of extended movements of the earth's axis during geologic eras. A displacement of the poles by even a few degrees requires maximum vertical movements exceeding 1 km. in order to restore the equilibrium figure of the earth. These movements, of course, do not produce mountains but have a tendency to shift the diameters of the earth into new positions. However, large strains would be connected with such an event, and, if great displacements of the poles occurred during the history of the earth, large strains would have been a consequence, especially in the meridian along which the poles were traveling.

A year ago, Mr. Joel E. Fisher published privately a small book, entitled *Problems in the Geology of Mountains*, as a scientific by-product of many seasons of high-mountain climbing. Resulting from more intimate and extended contact with névés and the upper reaches of glaciers than most professional geologists possess, his three chapters on *nieves penitentes*, Forbes dirt bands, and the origin of glacial cirques were a notable contribution to glacial geology, and the present writer reviewed the book for the *American Alpine Journal*.[25] A fourth chapter, "Shiftings of the Axis of Gyration of the Earth as an Originating Mountain-making Force," presented the thesis that extensive redistribution of earth mass—whether by erosion, deposition, accumulation of ice caps, uplifts, subsidences, or movements of magma—would shift the earth's axis of rotation and that this, in turn, would lead to the folding and uplift of mountain ranges. The prime question being the magnitude of the possible tangential forces, which are generally considered too small to be important in mountain-making, the reviewer suggested making quantitative tests of selected mountain systems by a

[22] G. H. Darwin, "On the Influence of Geological Changes on the Earth's Axis of Rotation," *Amer. Jour. Sci.*, Vol. XIII (1877), pp. 444–48.

[23] W. D. Lambert, Frank Schlesinger, and E. W. Brown, "The Variation in Latitude," *Physics of the Earth*, Vol. II: *The Figure of the Earth* (1931), pp. 266–67.

[24] Pp. 166–74 of ftn. 20.

[25] Vol. V, No. 3 (1945), pp. 422–25.

series of calculations based on reasonable assumptions of how much earth mass might be displaced by recognized geologic processes.

This Mr. Fisher has undertaken to do; and in an article to appear before this,[26] he presents among his results the estimate that a tilting of the earth's axis of gyration by 10′ may be expected to produce uplifts of the order of magnitude of the Alps-Caucasus-Himalaya, or the American Cordillera, and that the transportation of the widespread sediments of Cretaceous time may well have caused a 10′ tilt of the earth's axis. Still, one may suspect that during the slow transfer of this great bulk of sediment, isostatic and other internal adjustments might limit the amount of axis-tilting much more than the author has thought; but quantitative evaluation is not easy. On the whole, his method of testing, by calculating the change in bulge-lifting force, for various latitudes, consequent on a 10′ tilt of the axis of rotation, has not yet shown convincingly that there has been developed thereby sufficient intensity of tangential compressive stress in the outer earth crust to corrugate a geosyncline into a mountain system. Further analysis of the problem is highly desirable because, if Fisher is right, the results are of great importance.

If rotational forces should prove more important in orogenesis than heretofore thought possible, they would be a factor for consideration in the problem of lunar versus terrestrial diastrophism. On the smaller, slow-turning moon they are much weaker than on the earth. Transfer of lunar material by atmosphere and hydrosphere is lacking, thus eliminating that possible cause of axis tilting. Also, the ellipticity of the moon, instead of being adjusted to the satellite's present distance from the earth and present speed of rotation, is about what it should be were the moon only one-third as far from the earth as now, and rotating faster, which indicates that the moon has sufficient strength to maintain for a long period of time the shape acquired presumably under a different rotation and much stronger earth pull.[27] Forces connected with the moon's rotation should not be expected to fold its surface into mountain ranges.

[26] "A Kinetic Theory on the Origin of Orogenic Forces," *Amer. Jour. Sci.*, Vol. CCXLIII (1945), pp. 606–13.

CONCLUSION

Diastrophism has not affected the surface of the moon in the same way, or to the same extent, as the earth. The dissimilar behavior must have resulted from different governing conditions. The most obvious differences between the two bodies which might have been responsible for the very different diastrophic manifestations have been considered briefly in reconnaissance fashion. The differences are great, but each ramifies into various complicating factors which must be understood and evaluated in reaching any firm conclusions. The general problem must be broken into its component parts, each of which will require careful study. But, in any case, since lunar diastrophism has been the product of lunar conditions, as terrestrial diastrophism has been the product of earth conditions, comparative studies of moon and earth will enable us to survey certain aspects of the earth's deformation with the added perspective of another point of view.

ACKNOWLEDGMENT.—The writer wishes to express his indebtedness to Dr. Otto Struve, of the Yerkes Observatory, who kindly supplied many excellent photographs of the moon, only three of which are here reproduced as illustrations.

[27] Pp. 37–38 of ftn. 20.

THE PITTSBURGH-POTTSVILLE BOUNDARY

GEORGE H. ASHLEY
State Geologist of Pennsylvania

ABSTRACT

The base of the Brookville coal (or the top of the underlying Homewood sandstone) has long been the accepted Pittsburgh-Pottsville (Upper-Lower Pennsylvanian) boundary in the Appalachian bituminous coal fields. But increasingly for the last forty-five years, detailed studies have shown that the boundary has been drawn at many horizons, some over 500 feet apart in the same section, owing to differing correlations. The reasons for these diverse correlations are given; and as the simplest solution of the problem, it is proposed to shift the boundary to the base of the Lower Kittanning—No. 5 Block coal, believed to correlate with the Buck Mountain bed, whose base forms the boundary at the type Pottsville locality at Pottsville, Pennsylvania.

THE BROADER PROBLEM

The Pennsylvanian system of the Appalachian region has from the beginning of its study been divided into two series. The upper, which contains the Monongahela, Conemaugh, and Allegheny groups, was called the "Coal Measures" in the early literature, or more recently the "Pittsburgh series."[1] The lower series, at first known as the "Conglomerate," has long been called the "Pottsville." The line between these series was drawn originally at the base of "the lowest coal seam"; and it was assumed that this bed was at the same horizon in the anthracite, Broad Top, and bituminous areas. This much appears in the *First Annual Report* of the Rogers Survey in 1836 (pp. 16–17). Today, owing to a number of causes, the boundary has been drawn at many horizons, some as much as 500 feet apart in the same section. This paper undertakes to resolve these differences and to present a satisfactory, uniformly defined boundary.

DISCREPANCIES IN PLACEMENT OF BOUNDARY

In 1900 David White[2] pointed out that the top of the Pottsville, as then drawn in the Northern Anthracite field and in the bituminous fields, did not correspond with the boundary as drawn at Pottsville.

According to the evidence of the plants, the beds of the basal portion of the Allegheny series —as high as the Clarion coal in the bituminous basins of western Pennsylvania—and the terraines extending from Coal A to at least as far as Coal C in the Northern Anthracite field, were laid down prior to the deposition of the roof shales of the Twin (Buck Mountain) coal, which forms the boundary in the type locality.

Time has shown that the problem and practice is much more complicated than is indicated by White's statement. The irregularities of the beds and the lack of persistent key rocks and of short-lived plant and animal species, by which to distinguish one horizon from another, have resulted in the conditions shown graphically in Figure 1.

The boundary has been placed at different horizons for four reasons:

1. As pointed out by David White, errors all due to assuming that the lowest workable coal bed in the several fields correlates with the Buck Mountain bed

[1] G. H. Ashley, "A Geologic Time Scale," *Eng. and Min. Jour. Press*, Vol. CXV (1923), pp, 1106–8.

[2] "Stratigraphic Succession of Fossil Floras of the Pottsville Formation in the Southern Anthracite Coal Field, Penna." *U.S. Geol. Surv. 20th Ann. Rept.* (1900), Part II, pp. 829–30.

at Pottsville; or, quite as often, that the massive sandstone underlying the minable coal beds is at the same horizon as the massive sandstone underlying the Buck Mountain bed at Pottsville. This has led to using the top of the Homewood (secs. 3, 5, 6) of the upper Connoquenessing (secs. 3–6), and of the Roaring Creek sandstone (secs. 13–17) at three different horizons, none of which correlates with the massive sandstone at the top of the Pottsville at Pottsville.

2. The extreme irregularity of the beds lying below the level of the Buck Mountain–Lower Kittanning coal has made it difficult to trace these beds from county to county or often from one valley to the next. This has caused many local variations in the mapping of these beds. Then, as discussed later, detailed mapping has shown that the Brookville coal of the middle Allegheny Valley is the Upper Mercer coal of Beaver Valley, 40–50 feet or more below the coal mapped as Brookville in the Beaver Valley.

Figures 2, 3, and 4 reveal in graphic form the irregularity of the Mercer coals ("Brookville" of recent folios in Allegheny Valley). The sections of Figure 2 were measured by Charles K. Graeber in the new Humphrey clay quarry 1½ miles southeast from the center of Brookville. Figure 3 shows sections taken near Burly, in southeastern Clearfield County. These show the tendency of at least one of the Mercer coals to divide or run together or disappear. Figure 4, sections near the Pennsylvanian Railroad station at Clearfield, shows also the variability of the A (Brookville) coal within a short distance.

3. The slow vertical changes in the fauna or flora over large intervals have made difficult the correlation of beds, from point to point, by fossils. Thus, a study of the Pottsville fauna in Ohio by Helen Morningstar[3] showed that (see sec. 10), of 35 species in the Lowellsville limestone below the Lower Mercer, all but 6 occur in the Lower Mercer. Of 65 species in the Upper Mercer clay bed, all but 7 are in the Lower Mercer. Of 94 in the MacArthur limestone (equal to Putman Hill, according to Wanless), all but 9 are common with the Lower Mercer; and of 52 in the Black Flint, which is today placed above the Putman Hill, all but 3 are found in the Lower Mercer horizon. Likewise, David White pointed out that it was easy to distinguish the differences in the plants at the Kittanning horizon or below the Lower Mercer horizon, but not between the intermediate horizons. White depended largely on minute differences too small to serve even as a basis for subspecies to distinguish one flora from another. The writer is one of many who put much weight on White's age determinations because of his long experience and close study of the Pennsylvanian plants. Thus, in a letter to David Reger of July 5, 1929, White states: "1. Coal No. 4 of Carter and Boyd Counties, Kentucky, is Upper Mercer (Section 12). 2. So is the Lower Torchlight coal without possibility of question. 3. Zaleski flint I have regarded as Kanawha black flint, = Mercer." See sections 12–16. If White is right, then the Winifred coal of West Virginia cannot possibly correlate with the Brookville coal of Ohio or northwestern Pennsylvania, and the Winters and Ogan coals = Upper and Lower Mercer and the "Clarion coal" (sec. 10) are the Brookville (Fig. 5). See also Morningstar,[4] who draws the top of the Pottsville at the base of the coal above the black flint

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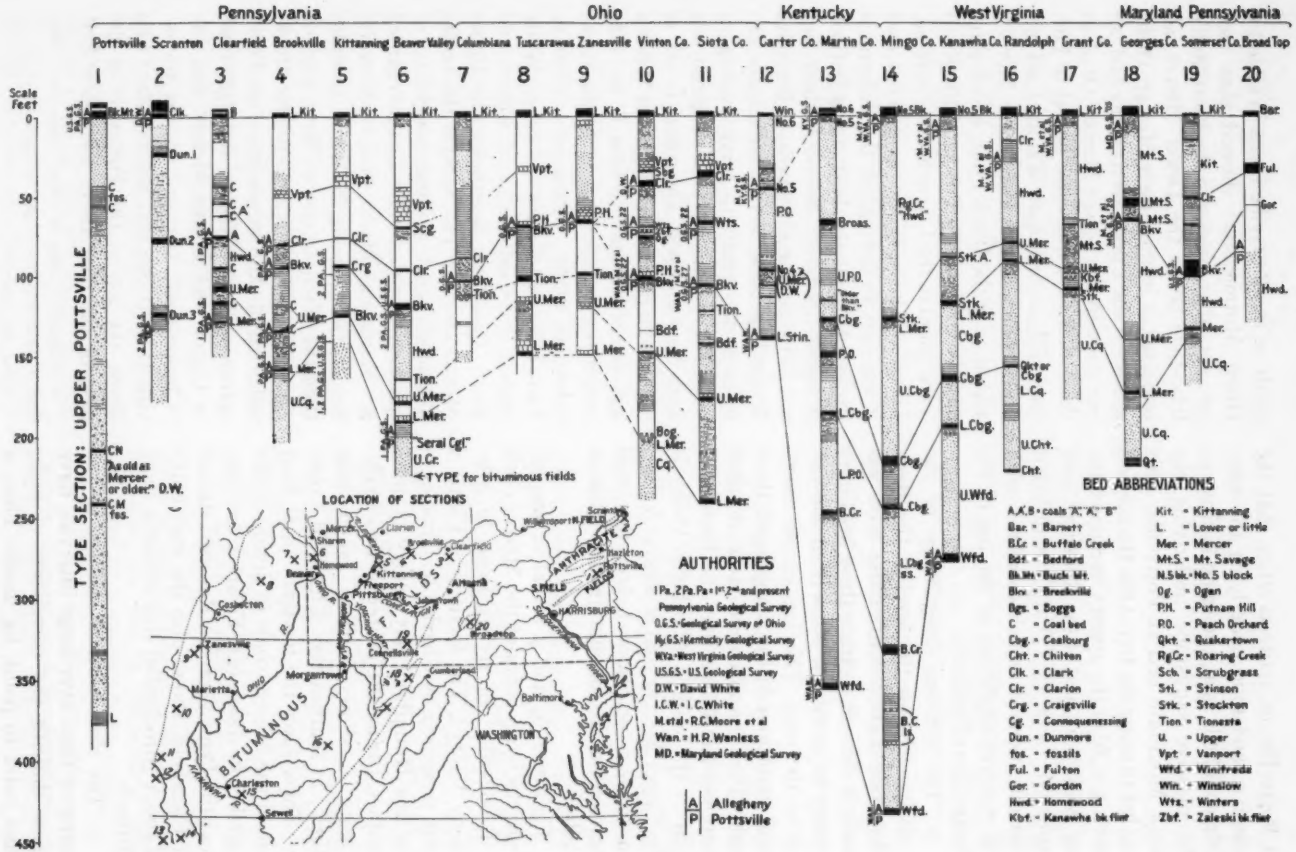

FIG. 1.—See legend on facing page

(secs. 10 and 11). The Kentucky and West Virginia geological surveys (secs. 12–17) have accepted and use White's correlations, claiming that they are in accord with their own tracings.[5] These instances are cited simply as evidences of the difficulties encountered in attempting to make correlations by means of fossils. Wanless[6] used the most modern methods except detailed field tracing.

4. On the other hand, as shown in Figure 5, if, as correlated by White, the Sharon coal of Pennsylvania, 250–300 feet below the Lower Kittanning, is the stratigraphic equivalent of the Sewell or the Iaeger coals of southern West Virginia, 1,900–2,300 feet below the No. 5 Block, it would seem more reasonable to consider that the entire northwestern Pennsylvania section had been thickened in West Virginia rather than that the lower part was tremendously thickened while the upper part had been thinned, as would be necessary if the Roaring Creek sandstone correlates with the Homewood and the Stockton coal is the same as the Lower Mercer. This would favor Wanless' correlation over the others.

[5] D. B. Reger, *County Reports: Mineral and Grant Counties, W. Va. Geol. Surv.* (1924), pp. 250–52.

[6] "Pennsylvanian Correlations in the Eastern Interior and Appalachian Fields," *Geol Soc. Amer. Special Paper 17* (1939).

PROPOSED DEFINITION OF BOUNDARY

I propose that the base of the clay under the Buck Mountain coal and of

FIG. 1.—Sections to bring out the varied usage in drawing the boundary between the Pittsburgh and Pottsville series or between the Allegheny and Pottsville. The various boundaries in use are indicated by the *A* over *P* at the left side of each section. This varied practice has led to the belief that a solution is needed.

Location and source of sections:

1. Pottsville, Pa., Southern Anthracite field, D. White, *U.S. Geol. Surv. 20th Ann. Rept. of the Director*, Part II, Pl. CLXXXI.

2. Scranton, Northern Anthracite field, *2d Geol. Surv. of Pa.*, Vol. AA: *Northern Anthracite Atlas III*, Columnar Section Sheet No. IX, Sec. V. Lower boundary by Second Geol. Surv.; upper, by D. White.

3. Clearfield, G. H. Ashley, *Pa. Geol. Surv. Bull. M6* (1932), Part II, p. 158. Lower boundary by Rogers; upper, by Second Geol. Surv. and later.

4. Brookville (comp.). See *Pa. Geol. Surv. Atlas A54* (1942), p. 62, Brookville quadrangle. (See discussion.)

5. Kittanning, Charles Butts, *U.S. Geol. Surv. Bull. 276* (1906), Pl. V, pp. 32–35. Intervals checked by measuring intervals on the map and averaging. Lower by First and Second Pa. Surv. and U.S. Geol. Surv.; upper by Second Surv. by miscorrelation.

6. Beaver Valley (comp.). See *Pa. Geol. Surv. Atlas 3*(1929), pp. 35 and 47, New Castle quadrangle.

7. Columbiana County, Ohio, W. Stout and R. E. Lamborn, *Ohio Geol. Surv. Bull. 28* (4th ser.; 1924), p. 51.

8. Tuscarawas County, Ohio, E. Orton, *Ohio Geol. Surv.*, Vol. V: *Economic Geology* (1884), p. 67.

9. Zanesville, Ohio, E. Orton. See p. 96 of ftn. 14.

10. Vinton County, Ohio, W. Stout, *Ohio Geol. Surv. Bull. 31* (4th ser.; 1927), pp. 66, 67, and 160.

11. Sciota County, Ohio, H. R. Wanless, *Geol. Surv. America Special Paper No. 17* (1937), Pl. IV, sec. 3.

12. Carter County, Ky., H. R. Wanless (see ftn. 17), Pl. IV, sec. 6 (lower boundary). D. White identifies Ky. No. 4 coal as Upper Mercer (see discussion). No. 5 coal, therefore, must be the Brookville. The Ky. Geol. Surv. has adopted that boundary in contrast with Wanless' use of the Lower Stinson. The same is true for Martin County and those following.

13. Martin County, Ky., Wanless (see ftn. 17), Pl. IV, sec. 9.

14. Mingo County, W.Va., Wanless (see ftn. 17), Pl. IV, sec. 18.

15. Kanawha County, W.Va., Wanless (see ftn. 17), Pl. IV, sec. 22.

16. Randolph County, W.Va., *W.Va. Geol. Surv. County Rept. 1931*, pp. 223, 232, and 233.

17. Grant County, W.Va., D. B. Reger, *W.Va. Geol. Surv. County Rept. 1924*, pp. 184–87, Mineral and Grant counties.

18. Georges Creek Basin, Md., C. K. Swartz, *Md. Geol. Surv.*, Vol. XI (1922), pp. 125 and 126. Note change from report of same survey in 1905.

19. Somerset County, Pa., G. B. Richardson, *U.S. Geol. Surv. Fol. 224* (1934), Somerset-Windber quadrangle.

20. Broad Top Field, J. H. Gardner, *Topog. and Geol. Surv. Comm. Rept. 10* (1913), p. 26.

FIG. 1.—See legend on facing page

other coals correlated with it be made the accepted plane between the Pittsburgh and the Pottsville series. Therefore, it is necessary to justify the recommended change. The change is proposed solely because of the past and

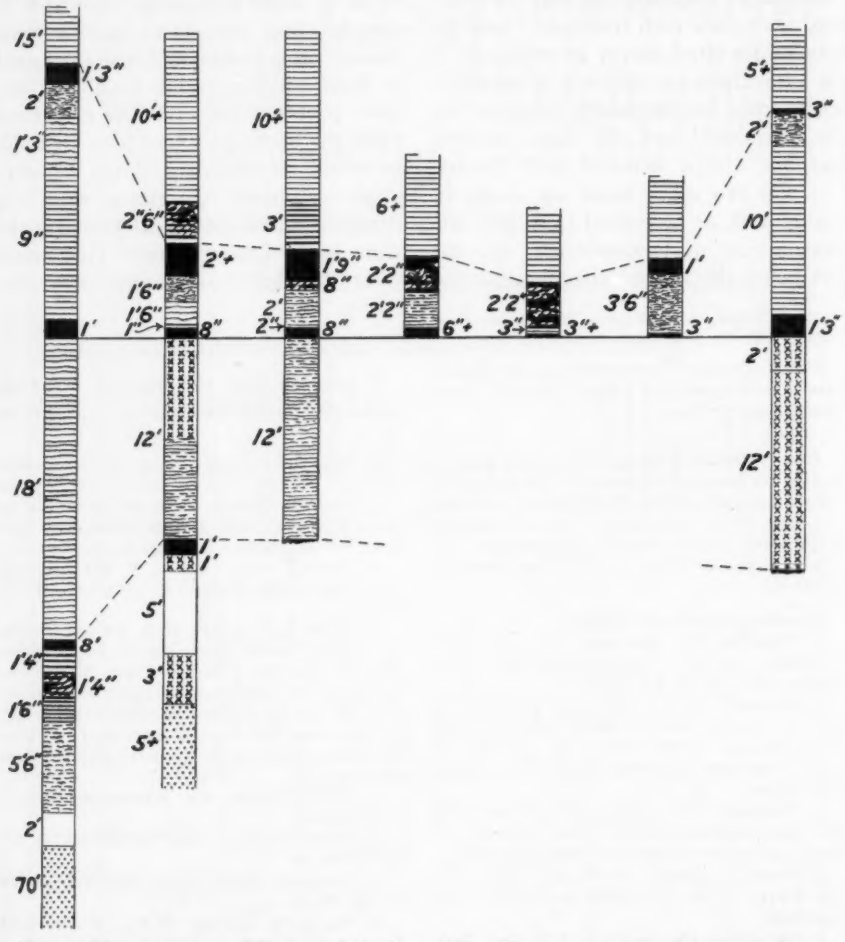

FIG. 2.—Measurements on Mercer coals in face of New Humphrey quarry, 1½ miles southeast of Brookville (Graeber).

Throughout the bituminous fields the base of the "Brookville coal" or the top of the underlying "Homewood sandstone" has been widely used as the top of the Pottsville. The proposed definition departs completely from that practice. present variations in usage and because there seems to be no way of resolving those differences except by a detailed and painstaking tracing of the beds in the field, supplemented by considerable drilling data. Such a survey may be a long

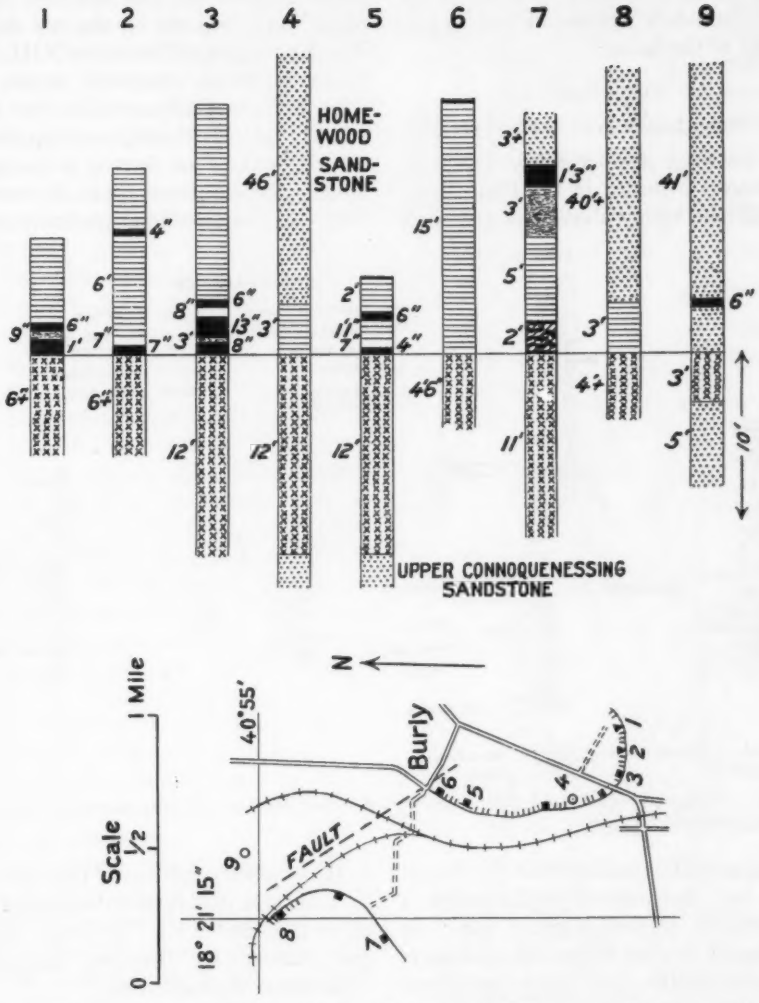

FIG. 3.—Measurements on Mercer coals in strippings and drillings near Burly in southeastern Clearfield County. These are exposed only because of the commercial value of the refractory clay shown in sections.

time in the future. The discussion which follows seeks to trace the history of the varied boundary definitions and to present all of the facts.

DISCUSSION

FIRST GEOLOGICAL SURVEY OF PENNSYLVANIA

In his *First Annual Report* (1836, p. 17) Rogers included in the Coal Measures all the beds "above the red shale strata, notwithstanding that the lowest rocks are destitute of coal through a thickness of several hundred feet." In the *Second Annual Report* (1837) Rogers presented a table, from which the following is taken:

TABLE OF STRATIFICATION (IN PART)*

		Feet
XIII	"Shales, sandstones, and seams of Anthracite coal"	6,750
XII	"Coarse quartzose conglomerate," etc.	1,400
XI	"Red shales and soft argillaceous red sandstones".	2,949

* Rogers, *2d Ann. Rept.* (1837), opp. p. 19.

Formation XII is described as "subjacent to all of the coal measures of the State" and "reposes on the red shale." The description of Formation XIII is devoted to certain structural details and does not specifically mention the individual coal beds. Nowhere in the annual reports of the First Survey is the upper limit of the conglomerate in the anthracite fields clearly defined, probably owing to the crushed condition of the coals, except to state that it included everything up to the base of the "first coal" of the coal measures. By "first coal" was meant "the lowest workable coal."

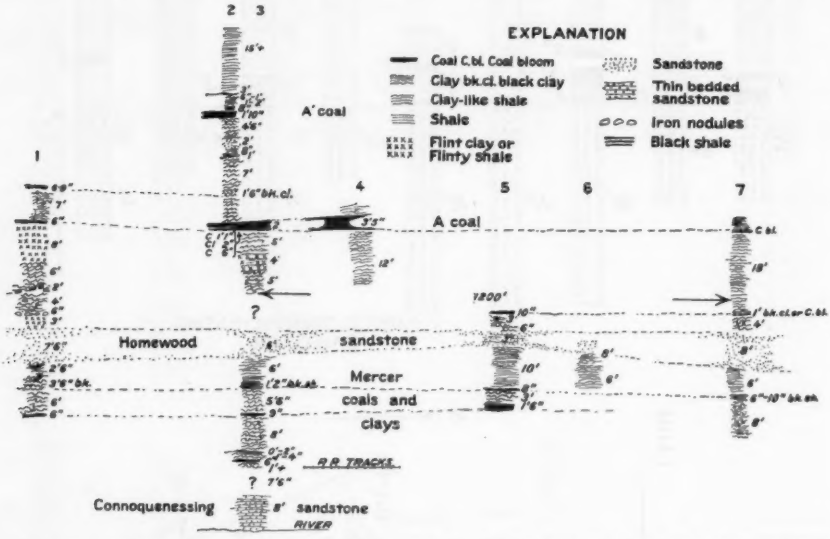

FIG. 4.—Exposures of coal and clay at Mercer and Brookville horizons, just east of Pennsylvania Railroad station at Clearfield.

In the bituminous fields the line between formations XII and XIII was first drawn in Rogers' *Fourth Annual Report* (1840) (p. 177), which describes the "Coal Measures—Allegeheny Series" along Allegheny River northward from Pittsburgh, in descending stratigraphic order. "No. 6—Coal" is the "first workable coal seam of the Allegheny series"

and is clearly the Upper Freeport of today; "No. 12—Coal" is Lower Kittanning; "No. 15—Fossiliferous Limestone" is the Vanport; "No. 17—Coal" is the Clarion; "No. 18—Shale and argillaceous sandstone" "about forty feet" thick, overlies "No. 19—Coal"; and beneath this is "Formation XII—White Sandstone." Number 19 is "the lowest workable coal hitherto found in the series along the Allegheny River." This seems clear enough; since "No. 17—Coal" was 20 feet below the Fossiliferous limestone (Vanport) and "No. 19—Coal" 40 feet lower, the top of Formation XII should be about 60 feet below the limestone or in the position of the top of the Tionesta sandstone as given in Rogers' 1858 section. But his description of "No. 19—Coal" fits the Upper Mercer coal of today, for it crops out "in a northeast–southwest direction through Mercer, Venango, and Clarion Counties." Specific locations given are all in Venango County, and they obviously refer to the Upper Mercer coal as now identified in that area. But the Upper Mercer coal averages 100 feet or more below the Vanport limestone in that area, instead of 55 feet, as indicated in the Rogers' section given below.

In the final report of 1858 Rogers gives the following compiled section of his basal Allegheny series.

This quoted section leaves no doubt that in the end Rogers drew the line between formations XII and XIII in the bituminous coal fields at the base of the Mercer member; nor is there any doubt

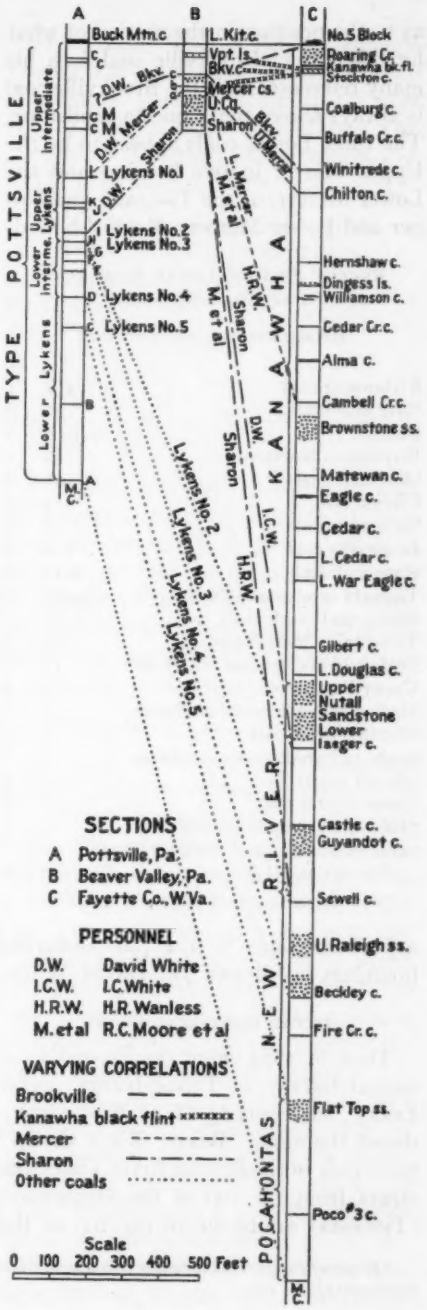

FIG. 5.—Pottsville sections in the Southern Anthracite field of Pennsylvania, Beaver Valley, Pennsylvania, and southern West Virginia, to show the variable thickness and content of the series. The letters *a*, *b*, *c*, show the position of the Brookville (*a*), Upper Mercer (*b*), and Lower Mercer (*c*) coals, all of which have been called "Brookville" in recent literature on western Pennsylvania.

as to the position in the section of what he called the "Brookville coal." In his many references to it the Brookville coal is always above the Tionesta sandstone. The three Porter coals appear to be the Upper Mercer in two benches and the Lower Mercer, or the Tionesta, and Upper and Lower Mercers. Rogers' boundary corresponds to the paleobotanical boundary as drawn by David White.

ROGERS' SECTION, LOWER ALLEGHENY RIVER COAL MEASURES*

FORMATION XIII (LOWER PART)

	Ft.	In.
Kittanning coal	3–4	0
Slate and shale	30	0
Iron ore	4 in. to 6	0
Ferriferous limestone	15	0
Slate and shale	30	0
Clarion coal	3–4	0
Slate and shale	25	0
Brookville coal	1–2	0
Slate and shale	5–15	0
Tionesta sandstone (massive)	50–60	0
Brown and black shale	2–25	0
Tionesta or Mercer coal	1–4	0
Shale and argillaceous limestone	15	0
Upper Porter coal	1	3
Shale and argillaceous sandstone	15	0
Middle Porter coal	1	0
Shale and argillaceous sandstone	15	0
Mercer limestone	2	0
Lower Porter coal	1	8
Shale and argillaceous sandstone	15	0
Seral sandstone and conglomerate (Formation XII)	100	0

* *Ann. Rept.* (1858), Vol. II, pp. 476–77.

SECOND GEOLOGICAL SURVEY

Then in 1874 came the Second Geological Survey of Pennsylvania, under Lesley. In report Q,[7] I. C. White introduced the name "Beaver River Group" to include in the Beaver River Valley the strata from the top of the Homewood (Tionesta) sandstone to the top of the Sharon sandstone, but with this qualification by Lesley: ". . . . provided that the term has the same systematic value as those of the *Freeport, Kittanning,* and *Clarion Groups,* and that the group is the *lowest part* of the well-established *Allegheny River Series.*—J. P. L." (italics Lesley's). This would carry the Allegheny River series down to the top of the Sharon sandstone. It was then thought that the Sharon conglomerate might be the top of Formation X or Pocono (No. XI, Mauch Chunk, is missing in that part of the state).

In volume QQ,[8] I. C. White makes no mention of the Allegheny River series, but of the "Lower Productive Coal series," including from the top of the Upper Freeport coal to the top of the Tionesta (Homewood) sandstone, followed by "the Conglomerate Measures, No. XII," identical with the Beaver River group of the preceding volume. Of the Brookville coal, White says (p. 51):

> Below the Clarion, we generally find nothing but sandy shales until we come down to the Tionesta, but sometimes we get a coal resting immediately upon the latter stratum, and I have identified it with the Brookville bed of the First Survey. The bed occurs at an interval of 53 feet below the Ferriferous limestone at this locality, and it is never more than that, but sometimes less.

This agrees with Rogers' position of the Brookville (see above) but does not agree with Rogers' top of Formation XII. It may be explained that at that time I. C. White's work had been confined to the Beaver Valley, where the Homewood sandstone is commonly massive and conspicuous. In the Allegheny Valley that sandstone is generally much less massive, and the conspicuous sandstone is the underlying Connoquenessing sandstone (Formation XII of Rogers),

[7] *Report of Progress in the Beaver Bituminous Coal-Fields of 1878,* p. 66.

[8] *The Geology of Lawrence County, 1879,* p. 27.

as in his section. I. C. White[9] was more impressed by the sandstones than by the accompanying coal beds, which, as a rule, are not impressive.

The confusion existing in the late seventies is shown by W. G. Platt's report H4,[10] which defines the Allegheny River coal series as including the Lower Barren Measures and down to and including the Pocono sandstone (Vespertine). The section includes the "Lower Productive Coal Measures" and "Pottsville conglomerate (Seral), XII." The "Allegheny River series" is not used in the later Q and H reports, which cover the area in question. In those reports "Lower Productive Coal Measures" and "Pottsville—No. 12" were used, the former including strata down to the top of the Pottsville conglomerate, of which the Homewood sandstone was considered to be the top member with the Brookville coal just above. This is distinctly different from Rogers' practice (see above), in which he put the top of Formation XII under the Mercer coals. However, by 1885, the use of the base of the Brookville coal or the top of the underlying Homewood (Tionesta or Piedmont) sandstone had been accepted not only in Pennsylvania but in Ohio as well.[11]

In 1895 the work of the Second Geological Survey of Pennsylvania was summed up in a *Final Summary Report* by Lesley and others, where in Volume III, Part I, page 1920, it says: "The bottom of the Buck Mountain or Red Ash bed, the first coal bed overlying the conglomerate, has been taken as the upper limit of XII." This is definite enough. The section in the bituminous coal fields is given in Volume III, Part II, page 2156. The basal part of the "Lower Productive or Allegheny River series, No. XIII" is as follows:

LOWER PART OF "ALLEGHENY RIVER SERIES, No. XIII" (D'INVILLIERS)

Kittanning lower coal bed B
Kittanning sandstone
Buhrstone iron ore
Ferriferous limestone
Clarion coal bed A'
Brookville coal bed A
Homewood sandstone: Top of Conglomerate No. XII

This section is strictly in accord with the Rogers section so far as the "Homewood sandstone" is concerned. But it differs in putting the boundary between the Allegheny River series and Formation XII below the Brookville coal rather than below the underlying Mercer coals, as was done by Rogers.

UNITED STATES GEOLOGICAL SURVEY

In 1891 appeared *U.S. Geological Survey Bulletin 65*, "Stratigraphy of the Bituminous Coal Fields of Pennsylvania, Ohio, and West Virginia," by I. C. White, in which Allegheny River series is revived as synonymous with Lower Coal Measures, including down to the Pottsville conglomerate (XII) of which the Homewood sandstone formed the top. Apparently I. C. White assumed that Roger was in error in placing the boundary below the Mercer coals.

In 1904 the U.S. Geological Survey published the Kittanning folio; and in 1906, *Bulletin 279* on the "Economic Geology of the Kittanning and Rural Valley Quadrangles," both by Charles Butts, in which the Pottsville is described as including the Connoquenessing sandstone, Mercer shale, and Home-

[9] "Stratigraphy of the Bituminous Coal Fields of Pennsylvania, Ohio, and West Virginia," *U.S. Geol. Surv. Bull. 65* (1891), p. 19.

[10] *Report of Progress in Indiana County, 1878*, p. 35 (2d Geol. Surv. of Pa.)

[11] Edward Orton, *Ohio Geol. Surv.*, Vol. V: *Economic Geology* (1884), pp. 1–8.

wood sandstone (pp. 30–31). The Allegheny formation contained, from the bottom up: the Brookville coal, Craigsville coal, Clarion sandstone, Clarion clay, Clarion coal, Vanport (Ferriferous) limestone, Kittanning sandstone, Kittanning fire clay, Lower Kittanning coal, and so on (pp. 32–35). This area, studied by Butts, lies immediately southwest of Brookville, and it might be presumed that "Brookville coal' of the Kittanning quadrangle is the true Brookville. Butts described the three lower coals as follows: Brookville coal, "a generally worthless coal lying from 10 to 20 feet above the top of the Pottsville"; Craigsville coal, "two miles northwest of Craigsville is a coal 3 feet thick 50 feet below the Vanport limestone" (it was seen at only two other places in the two quadrangles); Clarion coal, "so far as known, probably rarely exceeds a foot in thickness throughout the quadrangles."

The Kittanning-Brookville area is the type locality for the basal part of the Allegheny formation. In view of the inconsequential character of the three beds just described, is it any wonder that there was confusion as to which bed was "the lowest workable coal seam"?[12] Note that, as against Rogers' final section, in which the "Brookville coal" is 60 feet or less below the Vanport limestone, in the Kittanning, Rural Valley, Foxburg, and Clarion folios, the "Brookville coal" averages from 85 to 112 feet or more below the Vanport limestone, while the Craigsville coal is in the position of Rogers' Brookville coal. It was this difference that first led the writer to question whether the Craigsville coal was not the Brookville coal of Rogers and of the Beaver Valley, where locally it is called the "Pardoe coal." But if the Brookville coal of the type area is one of the Mercers, it means that the "Brookville coal" of Beaver Valley, Southwestern Pennsylvania, Ohio, or northern West Virginia is not Brookville, and sections throughout that area must be revised. Before calling for such a revision, however, let us study the type area more closely.

[12] Rogers, *4th Ann. Rept.*, p. 198.

FOURTH GEOLOGICAL SURVEY OF PENNSYLVANIA (1919——)

The present Geological Survey has taken four steps toward solving this problem.

1. In 1921 B. Coleman Renick[13] traced the strata from the type section in Beaver Valley to Brookville in great detail, leading to the conclusion that

> the sandstone known as the Clarion is in reality the Homewood sandstone of the Beaver River section, and the sandstone called "Homewood" in the Foxburg-Clarion folio is the upper Connoquenessing sandstone of the Beaver River section. The coal called "Craigsville" coal along Allegheny River is the stratigraphic equivalent of the Brookville coal of the Beaver River section.

Because of two weak links in the chain of sections, no change was made in the stratigraphy at that time, pending the strengthening of those links.

2. From 1931 to 1934 Charles K. Graeber[14] surveyed the Brookville quadrangle, with results shown in Table 1. In 1936 and later R. E. Sherrill and others[15] mapped the Hilliards, Franklin, and Oil City quadrangles, tracing, with similar

[13] "The Correlation of the Lower Allegheny-Pottsville Section in Western Pennyslvania," *Jour. Geol.*, Vol. XXXII, No. 1 (1924), pp. 64–80.

[14] "Structure and Stratigraphy of the Brookville Quadrangle," *Pa. Geol. Surv. Bull. 120* (1939), p. 6.

[15] "Geology of the Oil and Gas Fields of the Hilliards Quadrangle," *Pa. Geol. Surv. Bull. 122* (1939), p. 4; "Geology of the Oil and Gas Fields of the Franklin Quadrangle," *Pa. Geol. Surv. Bull. M24* (1941), p. 7; "Geology of the Oil and Gas Fields of the Oil City Quadrangle," *Pa. Geol. Surv. Bull. M25* (1943), p. 7.

TABLE 1

TABLE OF INTERVALS OF LOWER ALLEGHENY GROUP IN PENNSYLVANIA ABOVE OR BELOW THE VANPORT LIMESTONE (IN FEET)
(Lower Kittanning Above; the Others Below)

Source of Sections	Lower Kittanning Coal	First Coal	Second Coal	Third Coal	First Sandstone	Fourth Coal	Fifth Coal	Second Sandstone
1858, Beaver Valley, Rogers	Kit. 45	.....	Cl. 33	Bkv. 58	Tion. 68	U.M. 133	L.M. 185	Seral 200
1880, Beaver Valley, L. C. White	Kit. 60	Sg. 5	Cl. 21	Bkv. 53	Hw. 56	U.M. 103	L.M. 132	U.Cq. 157
1905, Beaver Valley, DeWolf	L.K. 56	U.Cl. 5	L.Cl. 25	Bkv. 58	Hw. 60	U.M. 99	L.M. 130	U.Cq. 134
1921, Beaver Valley, Renick	.....	U.Cl. 13	L.Cl. 34	Bkv. 57	Hw. 58	U.M. 92	L.M. 119	U.Cq. 128
1921, Slippery Rock, Renick	.....	U.Cl. 10	L.Cl. 31	Bkv. 49	Hw. 50	U.M. 81	L.M. 109	.....
1939, Hilliards quadrangle, Sherrill	L.K. 45	U.Cl. 20	L.Cl. 35	Bkv. 60	.....	.....	Mer. 115	.....
1911, Foxburg quadrangle, Shaw	L.K. 45	U.Cl. 14	L.Cl. 36	Cr. 64	.....	Bkv. 102	.....	Hw. 112
1904, Kittanning quadrangle, Butts	L.K. 43	.....	Cl. 20	Cr. 50	.....	Bkv. 85	.....	Hw. 127
1921, Allegheny Valley, Renick	.....	U.Cl. 12	L.Cl. 34	Bkv. 71	Hw. 71	U.M. 84	L.M. 117	U.Cq. 130
1910, Clarion quadrangle, Lines	L.K. 32	.....	Coal 25	Coal 45	.....	Bkv. 98	.....	Hw. 108
1939, Brookville quadrangle, Graeber	L.K. 48	.....	U.Cl. 32	L.Cl. 45	Cl. 52	Bkv. 84	.....	Hw. 88
1944, Brookville quadrangle, Ashley	L.K. 45	.....	Cl. 30	Bkv. 47	Hw. 55	U.M. 81	L.M. 115	U.Cq. 125

* U. = Upper; L. = Lower; Bkv. = Brookville; Cl. = Clarion; Cr. = Craigsville; Cq. = Connoquenessing; Hw. = Homewood; K. *or* Kit. = Kittanning; M. = Mercer; Sg. = Scrubgrass; Tion. = Tionesta.

conclusions, the beds on the surface and filling one gap in Renick's work.

3. In 1944 the writer made certain field studies around Brookville. These results can be summarized in Table 1. Note here that the Lower Kittanning coal, with one exception, lies between 45 and 60 feet above the Vanport limestone. Below the Vanport are five coal horizons and two sandstone horizons, each in its own zone. The first coal is from 5 to 20 feet below the Vanport limestone; the second, from 20 to 35 feet; the third, from 45 to 65 feet; the fourth, from 80 to 105 feet; the fifth, from 110 to 135 feet. The matter is presented graphically in Figure 6.

Table 1 and Figure 6 show that the Brookville coal throughout this area was from 45 to 65 feet below the Vanport limestone and that the nomenclature of the Kittanning and later folios in that immediate area was in error.

Renick's work was of a very high order, the valley banks being mapped in great detail for every rock outcrop. His conclusions would have been accepted at that time but for two minor breaks—one over the crest of the Beaver-Allegheny divide, the other between Redbank and Brookville.

Sherrill's work on the coals was one phase of his study of oil and gas sands of Venango County. In a letter of October 2, 1943, Sherrill, after 7 years' work in that area, says:

> I have found no reason in my later work (Oil City) to deviate from my earlier conclusion that the Mercer of Mercer County is the Brookville of the Foxburg-Clarion. Whether or not this is the Brookville at Brookville is a question of which I have no evidence beyond the literature.

WHAT IS BROOKVILLE COAL AT BROOKVILLE?

The Brookville coal was first mentioned in Rogers' final report (1858), in the table already quoted under "First Geological Survey of Pennsylvania." On page 490 of the same report occurs the following:

> The Brookville Coal.—This bed, lying immediately upon, or a few feet above the Tionesta sandstone, has an irregular outcrop, coinciding in the main with that of the Clarion coal and Ferriferous limestone above it, and it will be best described with theirs.

In the same volume (p. 583) the Brookville coal is described as

> seen upon the hills back of the town (Brookville), and on the turnpike towards Clarion. It outcrops towards the fifth axis about 5 miles W. of Brookville, and measures 3 or 3½ feet in thickness; also around the sides of a high hill, 6 miles from Brookville on the Warren Road, 60 or 80 feet below the summit, upon which lie the fragments of the Ferriferous Limestone-bed and and its valuable ore.

FIG. 6.—Sections showing the relations of the sub-Lower Kittanning coals from Mercer County to Clearfield County.

1.* Lawrence Co., Pa., present survey, *A5*, Newcastle quadrangle (24 secs.) (Pls. VI, VII, and VIII).

2. Mercer Co., Pa., *2d Pa. Geol. Surv. Q3* (27 secs.).

3. Northern Butler Co., Pa., *Geol. Surv. Bull. 122*, Hilliards quadrangle (Gen. Sec., p. 4).

4. Clarion Co., *U.S. Geol. Surv. Bull. 454*, Emlenton and Foxburg quadrangles (5 secs. Pls. VI and VIII).

5. Clarion Co., *U.S. Geol. Surv. Bull. 454*, east of Callensburg, Foxburg quadrangle.

6. Clarion Co., southern ½ Clarion quadrangle, Pa., *Pa. Comm. Surv. Rept. 3*, p. 21 (Gen. Sec.).

7. Clarion Co., Limestone Twp., Brookville quadrangle, Pa., *Pa. Geol. Surv. A54*, Pl. 10, Fig. 2.

8. Jefferson Co., Summerville, Brookville quadrangle, Pa., *Pa. Geol. Surv. A54*, p. 47.

9. Jefferson Co., near Conifer, Brookville quadrangle, Pa., *Pa. Geol. Surv. A54*, Pl. 10, Fig. 5.

10. Jefferson Co., southeast of Brookville (Graeber and G. H. A.).

11. Clearfield Co., McGees Mills, Pa., *Pa. Geol. Surv. A65*, Punxsutawney quadrangle, pp. 29 and 30.

12.* Clearfield Co., top ½, Clearfield; bottom ½, Clearfield Creek, Pa., *Pa. Geol. Surv. Bull. M6*, Part II, p. 158.

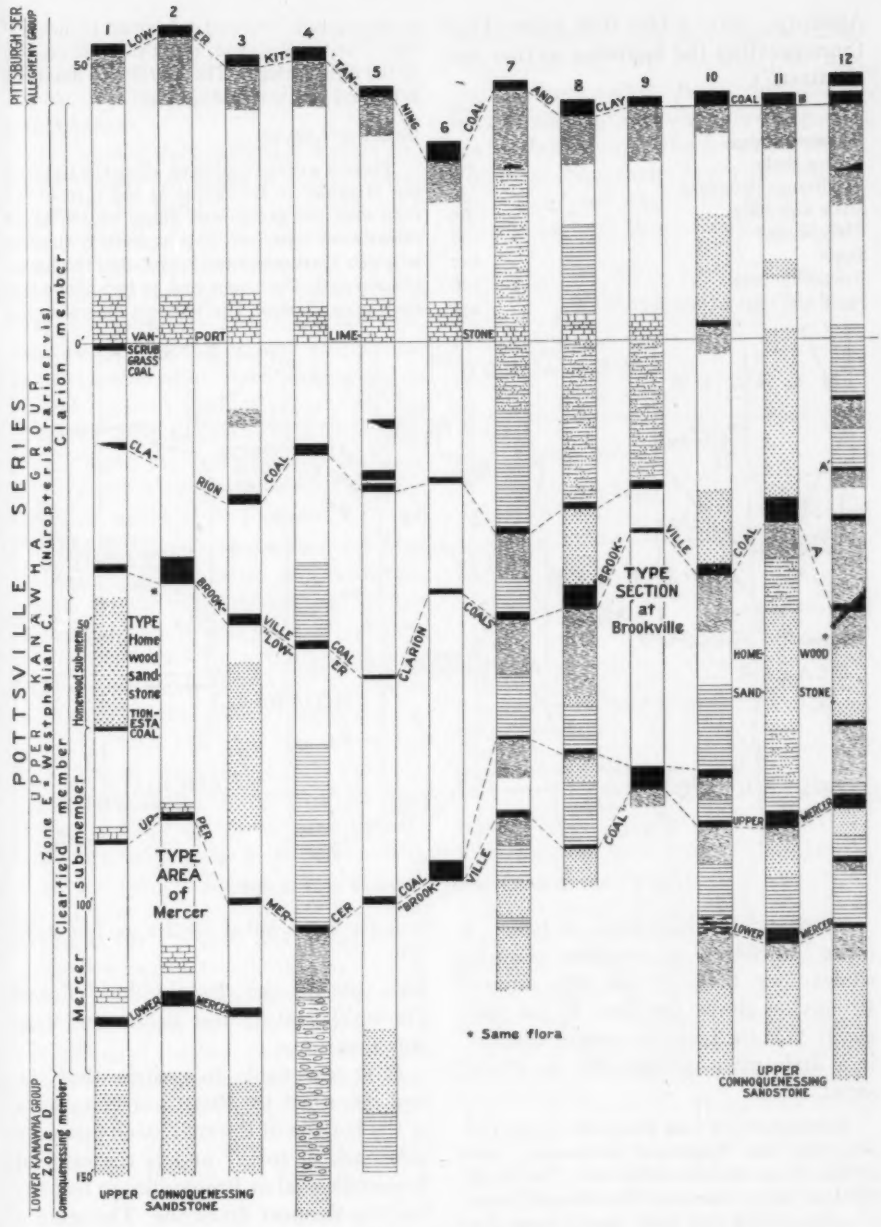

FIG. 6.—See legend on facing page

Again (p. 584): "One mile below Troy (Summerville) the following section was obtained":

	Ft.	In.	Total Feet
Kittanning coal	2	..	2
Brown shale	30	..	32
Ferriferous limestone	4	..	36
Shale and slate	30	..	66
Clarion coal	1	2	67
Shale	55	..	122
Brookville coal	3	6	126
Shale and slate to bed of creek	45	..	171

to the roadside, revealed only about 18 inches of coal. The Clarion seam, 1 foot thick, is exposed at the water trough. The Ferriferous limestone is crossed just beyond that place.

Graeber[17] says:

There is a caved coal bank along the Lakes to Sea Highway in Brookville at the turn of the road near the garage and filling station at an elevation of 1,450 feet. This is probably the coal to which Platt refers and is probably the Lower Clarion coal. The 1-foot coal 30 feet above it is the Upper Clarion. The Vanport limestone has

FIG. 7.—Sketch map showing location of sections in Fig. 6

"Seen on the hills back of town" is quite indefinite, as modern mapping shows four beds in the hills around Brookville above the level of its main street. "On the turnpike toward Clarion" is a little more definite. W. E. Platt[16] says:

Proceeding west from Brookville by the Corsica road the Homewood sandstone is first crossed at the outskirts of the town. The Brookville coal seam outcrops at Mr. Braden's house. .... An opening once made upon it here, close to the roadside, revealed only about 18 inches of coal. The Clarion seam, 1 foot thick, is exposed at the water trough. The Ferriferous limestone is crossed just beyond that place.

[16] "Jefferson County," *2d Geol. Surv. Pa. Rept.* (1881), p. 106.

[17] *Ibid.*, p. 50.

been dug in this hill at about 1,500 feet elevation.

This places the Brookville ("Lower Clarion") coal 50 feet below the Vanport limestone.

It is reasonable to assume that the coal described by Platt and Graeber is at the horizon of the coal "seen upon the hills back of town" and is the original Brookville coal at Brookville, 50 feet below the Vanport limestone. The section at Troy obviously lacks the Brookville

coal; and Rogers' assumption that the coal next below the Clarion was the Brookville, regardless of interval, was erroneous.

Remapping the area about Brookville, based mainly on Graeber's field notes, rechecked by hand level, and new road cuts revealed four coal beds below the level of the Vanport limestone. As the limestone is lacking for a considerable area immediately around Brookville, the usual three-dimension structural pattern was used in which every outcrop of coal must fit into its place with the structure, as letters must fit into a crossword puzzle. As a starter, all available drill records were plotted to get average intervals, as shown in Figure 8.

Intervals obtained from Figure 8 were then supplemented by field measurements. In the end the outcrop of the Lower Kittanning coal must everywhere be 50 feet above the hypothetical positions of the lacking Vanport limestone, and the four other coals at approximately 30, 47, 81, and 115 feet below the hypothetical position of the Vanport. The actual interval used varied from place to place according to available local information, such as drill records or several beds in the same hill. According to this mapping, the 4½-foot coal mined at the Pawneee and Yates mines, 3 miles south of Brookville, at 85 feet below the Lower Kittanning, is the Brookville coal; and the equally thick coal mined at Conifer, and 120 feet below the Lower Kittanning coal, is the Upper Mercer. It is obviously the Conifer (Upper Mercer) coal that Rogers called "Brookville" at Troy (Summerville) and that has been called "Brookville" in the Kittanning, Rural Valley, Foxburg, and Clarion folios and in the *Brookville Atlas*. Changing it in these five areas will be vastly simpler than to accept the "Brookville" of those quadrangles and

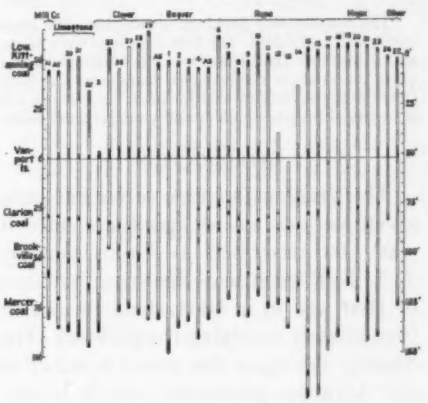

FIG. 8.—Skeleton sections of core-drill records in Brookville quadrangle. Names at the top are of several townships in which the drilling occurs. (Brookville is in Rose Township.) Numbers refer to section numbers in the *Brookville Atlas*.

require the revision of "Brookville" throughout western Pennsylvania, Ohio, northern West Virginia, and Maryland.

If this proposal is accepted, I propose that, until thoroughly established, the Allegheny group, down to the base of the Lower Kittanning coal, be called "Allegheny group, restricted," and that the Pottsville series, including all strata up to the base of the Lower Kittanning coal, be called "Pottsville series, extended."

AGE RELATIONS OF STANLEY AND JACKFORK FORMATIONS OF OKLAHOMA AND ARKANSAS

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ABSTRACT

The Stanley and Jackfork formations were recently correlated with the Pennsylvanian but their exact age is still a problem. The flora obtained from these formations is unlike any known flora in North America and is younger than that from the Wedington sandstone member of the Fayetteville shale (Chester) and older than that in Baldwin coal member of the Bloyd shale of the Morrow group (middle Pottsville). White considered the Stanley and Jackfork floras similar to those described from the Ostrau and Waldenburg series of central Europe, which are no younger than lower Namurian (E and possibly H zones).

INTRODUCTION

The Stanley-Jackfork series has been given various age designations since it was first described as Ordovician by J. A. Taff[1] because of limestone boulders of that age in a black-shale formation immediately overlying the Jackfork. The Stanley lies upon the upper member of the Arkansas novaculite, which is considered to be Devonian(?) by the United States Geological Survey, Devonian by some geologists, Devonian and Mississippian by others, and Mississippian by still others. The Jackfork is overlain by the Johns Valley shale or, where this is absent, by the Atoka formation. An accurate determination of the age of the Stanley-Jackfork has not been possible because of the complexity of the structure and the stratigraphy of the Ouachita Mountains and adjacent areas. However, the true Carboniferous age of the series was soon recognized, and for many years the formations were thought to be Mississippian.[2] This belief was influenced by the presence of Mississippian Caney shale[3] in Johns Valley, Oklahoma, overlying the Jackfork. But it is now recognized that the fragments of Mississippian shale at this locality are as truly boulders in the Johns Valley shale as are the large masses of limestone ranging in age from Ordovician to Pennsylvanian. The Johns Valley shale has been correlated with the Morrow group by Bruce H. Harlton,[4] although boulders of this age have been found in the shale. Since the beds in actual contact with the Stanley-Jackfork range in age from middle Pottsville above to Kinderhook (or Devonian?) below, they provide little or no definite evidence on the exact age of the formations.

A Pennsylvanian age for the formations has been suggested by a number of writers, although based on meager and seemingly inconclusive evidence. In 1927 a serious effort was made by Miser and others (including the writer) to secure sufficient fossil material to place a definite age on the series, and additional

[1] *U.S. Geol. Surv., Geol. Atlas, Atoka Folio 79* (1902), p. 4.

[2] Charles N. Gould, "Index to the Stratigraphy of Oklahoma," *Okla. Geol. Surv. Bull. 35* (1925); Hugh D. Miser and Charles W. Honess, "Age Relations of the Carboniferous Rocks of the Ouachita Mountains of Oklahoma and Arkansas," *Okla. Geol. Surv. Bull. 44* (1927).

[3] George H. Girty, "The Fauna of the Caney Shale of Oklahoma," *U.S. Geol. Surv. Bull. 377* (1909).

[4] "Micropaleontology of the Pennsylvania Johns Valley Shale of the Ouachita Mountains, Oklahoma, and Its Relationship to the Mississippian Shales," *Jour. Paleon.*, Vol. VII (1933), pp. 3–29.

collections were made during the years 1928–31. These collections, together with those obtained during previous years, were studied by David White (plants), Girty (invertebrates), and Harlton (microfossils). All of the available data have been ably presented by Miser.[5]

PALEOBOTANICAL EVIDENCE

The most useful of these collections yet obtained for correlative purposes are the floras. However, it should be borne in mind that systemic boundaries are drawn at different stratigraphic horizons when based on different classes of fossils. O. H. Schindewolf,[6] for example, pointed out that the Devonian-Carboniferous boundary, drawn on flora evidence, was placed in middle Tournaisian (about the base of the Osage), while, on the basis of corals, it was placed below the top of the Famennian, between Oberdevon Stufe IV and V. The line, based on brachiopods and trilobites, was placed between these two extremes, the latter approximating the base of the Kinderhook.

The Stanley-Jackfork floras formed the basis of two papers by David White,[7] the last of which was published, practically without modification, after his death early in 1935. In this paper the floras of the Stanley-Jackfork were compared with those from the Morrow, with the Wedington and other Chester floras, all from this country, and with the Upper Carboniferous floras of Upper and Lower Silesia, the Ostrau and Waldenburg series.

The Stanley-Jackfork, in spite of careful collecting for more than a quarter-century, had yielded only 34 species of plants—26 from the Stanley and 16 from the Jackfork (8 being common to the two formations). Of the 34 species, 19 are new and 8 are listed without specific designation. Regardless of the number of new species, no less than 18 from the list were closely compared to European species from the lower Upper Carboniferous, and the fauna was regarded as sufficiently comprehensive to determine the Pennsylvanian or Mississippian age of the Stanley-Jackfork with reasonable certainty.

The most extensive known Chester floras were obtained from the Wedington sandstone member of the Fayetteville shale of Arkansas,[8] the Chester series of the Mississippi Valley, and (unpublished) from the Appalachian section in West Virginia, Virginia, and Pennsylvania. D. White[9] considered the Wedington flora to consist of forms identical with or closely allied to others characteristic of the upper Chester; of unique forms; and of plants related to Pennsylvanian forms. He found two species, *Rhodea goepperti* and *Sphenopteris mississippiana*, common to the Wedington and Stanley-Jackfork floras; a lepidophyte, *Lepidodendron* cf. *L. wedingtonense*, was provisionally placed with this Wedington species. *Sphenopteris mississippiana* is probably the same as *S. hoeninghausii* of the Namurian of

[5] "Carboniferous Rocks of Ouachita Mountains," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XVIII (1934), pp. 981–85.

[6] "Die Liegendgränze des Karbons im Lichte biostratigraphischer Kritik," *Compt. rend. Cong. advance. des ét. de stratigr. carbonifère, Heerlen, 1927* (Liége, 1928), pp. 651–61.

[7] "Age of Jackfork and Stanley Formations of Ouachita Geosyncline, Arkansas and Oklahoma, as Indicated by Plants," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XVIII (1934), pp. 1010–17.

[8] White, "Fossil Flora of the Wedington Sandstone Member of the Fayetteville Shale," *U.S. Geol. Surv. Prof. Paper 186* (1937), p. 51.

[9] "Fossil Plants from the Stanley Shale and Jackfork Sandstone in Southeastern Oklahoma and Western Arkansas," *U.S. Geol. Surv. Prof. Paper 186* (1937), pp. 43–52.

Europe. As a result of his comparison of the Stanley-Jackfork floras with known Chester floras, White concluded that there is "little or no doubt that the Stanley as well as the Jackfork is younger than the entire Fayetteville shale and its Mississippian correlatives."

One of the best-known Carboniferous floras in North America is found in the roof of the Baldwin coal member of the Bloyd shale of the Morrow group in Washington County, northwestern Arkansas. This flora, first studied by Lesquereux in 1884, comprises about 125 species, which can be correlated with such middle Pottsville formations as the shales above the Lookout sandstone in Alabama and Tennessee, the Norton of Virginia, the Sewell of West Virginia, and the Caseyville of Illinois and Kentucky. A comparison of this flora with that from the Stanley-Jackfork shows that "the deposits are distinctly older than the plant-bearing shale of the Morrow group, including but two species that have been definitely recognized as present also in the shale." The Jackfork is then "referred to the early Pottsville, earlier than the coal-bearing shale of the Morrow group—specifically the lower Pottsville. . . . . Probably the whole of the Stanley shale falls in the same unit of the lower Pennsylvanian," regardless of the fact that "little is known either as to the flora of that portion of the Morrow group lying below the coal-bearing shale or as to marine faunas in the lower Pottsville of the eastern basins." Therefore, the Stanley-Jackfork flora, by comparison with known floras in formations not in actual contact with these formations, is "distinctly older than the plant-bearing shale of the Morrow" and "younger than the Wedington sandstone member" of the Fayetteville formation—in other words, older than middle Pottsville and younger than middle Chester.

Earlier, White was of the opinion that the formations were Mississippian,

> based largely on the parallelism in floral composition and the presence of closely related or identical floral elements in the Jackfork and Stanley and in the fully elaborated floras of the Waldenburg and Ostrau series (Culm) of the former Austro-Silesian region, which were then regarded as uppermost Lower Carboniferous.

Regardless of the position of these beds with reference to the European Upper and Lower Carboniferous boundary, the important fact is that the Stanley-Jackfork flora was considered to be most closely correlative with a European assemblage and not closely comparable with any known flora from either Mississippian or Pennsylvanian formations in America.

It should be pointed out that White's designation of the Pennsylvanian age of the Stanley-Jackfork was influenced by the transfer of certain beds of the Lower Carboniferous of Europe into the newly created Namurian series, the lower division of the Upper Carboniferous, by action of the Congrès pour l'avancement des études de stratigraphie carbonifère, which met at Heerlen, Netherlands, in 1927. He also "accepted the thesis of the essential equivalence of the American Mississippian and Pennsylvanian, respectively, to the European Lower and Upper Carboniferous, as revised by the Heerlen Congress of 1927.—EDITOR."[10]

INVERTEBRATE EVIDENCE

Invertebrates are extremely rare in the Stanley and Jackfork. A small collection made by Honess was regarded by Schuchert and Ulrich (each of whom examined the fossils independently) as

[10] *Ibid.*, p. 46.

inconclusive; but each favored a post-Chester age, possibly early Pennsylvanian.

The largest collection of invertebrates was by Miser[11] from the Jackfork near Little Rock and identified by Girty. Of the 28 forms listed by Girty from this fauna, 16 were given only generic designation (three-fourths of these were queried); and all of those given specific designation were qualified either by "?" or "aff." If the species themselves (or even genera) cannot be definitely recognized, it follows that their reference to known species described from other formations (either Mississippian or Pennsylvanian) must be regarded as uncertain.

Harlton[12] lists but does not figure a few species of microfossils from the Stanley-Jackfork. One, *Healdia caneyensis*, is known from the Chester of Illinois, and the similarity of other genera to Chester genera was recognized by him.[13] The Pennsylvanian aspect of most all late Chester faunas is well known.

All who have tried to solve the perplexities involved in the correlation of borderline formations are well aware of the great weight of evidence necessary for conclusive age determinations due to the early inauguration of new species and to the holdover of old species. For these reasons the invertebrate evidence produced so far from the Stanley and Jackfork should be regarded as inconclusive. A promising field for search for this evidence is in the upper Mauch Chunk beds of West Virginia and Virginia.

Since the first Heerlen Congress and since the papers of White, Miser, and others appeared, a number of factors have made a reopening of the question of the age of the Stanley and Jackfork seem advisable. The second Heerlen Congress, also devoted exclusively to problems of the Carboniferous, met in 1935, just subsequent to the International Botanical Congress at Amsterdam. Unlike the first congress, at which no American geologist was present, the second was attended by a number of geologists from this continent, among whom were C. A. Arnold and R. C. Moore. Much work had been done in the intervening eight years, as evidenced by the large number of papers in the *Compte rendu*.

At the first session in 1927 many delegates were of the opinion, as shown by their correlation charts, that the Ostrau and Waldenburg series occupied all of the Namurian (and probably more).

> Thus in the Namurian, defined as it has been agreed, it would be necessary to include the Waldenberg beds or strata and certainly a part of the Ostrau beds or strata. It is not impossible that the upper Ostrau beds belong to the Westphalian. Some delegates consider this conclusion even probable. As for the definite solution, it will result from new researches based on more complete materials and especially more systematic collections, materials which, actually, are totally missing in that which concerns the Ostrau beds.[14]

One delegate, Arnold Markowski,[15] even went so far as to include the Dinantian with our Pennsylvanian! However, no serious attempt was made to correlate the American section with the European section.

The second congress, owing to the

[11] *Ibid.*, pp. 989–91.

[12] "Carboniferous Stratigraphy of the Ouachitas with Special Study of the Bendian," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XVIII (1934), pp. 1035–37.

[13] *Ibid.*, p. 1021.

[14] K. Pattiesky, "Discussion générale," *Compt. rend., Cong. avance. des ét. de stratigr. carbonifère, Heerlen, 1927* (Liége, 1928), p. xxxix.

[15] "Coup d'œil sur la structure du bassin houiller polonais," *Compt. rend., Cong. avance. des ét. de stratigr.-carbonifère, Heerlen, 1927* (Heerlen, 1928), pp. 481–85.

presence of well-known American geologists and to the visit of W. J. Jongmans to many important American Carboniferous localities before the sessions, reached a much better understanding of the relationship between the Carboniferous of the two continents. The research on faunas, as well as on floras, had been greatly advanced since the first meeting, as shown by the work on the goniatites, corals, brachiopods, etc.

W. J. Jongmans and W. Gothan[16] in their "considerations of the results" of the second congress, presented a correlation table, which is given in part in Table 1. This table was drawn largely from a paper presented at the congress by R. C. Moore.[17]

TABLE 1

	Europe		North America
	~~

be noted that the E and H zones (*Eumorphoceras* and *Homoceras*) are shown to be Mississippian, corresponding to our upper Chester. Pattiesky[18] stated in his report at the second congress:

> To the E-zone belong the non-bedded 400 m thick Hultschin formation as well as the greater part of the 3,000 m thick Ostrau formation. Only the uppermost horizons of the Ostrau formation are likely to be connected with the H-zone.

careful faunal study of the Ostrau, delimited the series by the Sudenten disconformity at the base and placed the upper limit at a "?Discordanz" at the line separating the horizon of *Cravenoceras edalense* from that of *Eumorphoceras bisulcatum*, in the lower part of E_2. This line appears to be in the lower part of the lower Sabdenian of England and within the Elvira group of the type area

TABLE 2

Age		Formation	Zone
WESTPHALIAN	V_β	Karwin beds	Doubrava
NAMURIAN	V_α–IV_ϵ IV_α–IV_δ		Suchá Sattelflöz
	IV_1–H	Upper Ostrau beds	Poruba Jakewetz
	IV_1–E	Lower Ostrau beds	Hrusöv Petřkovice
	to	Hultschin beds	
	IV_1–S	Upper Wagstadt beds	
VISÉAN	III_γ	Lower Wagstadt beds Gratz greywacke	
	III_β	Posidonien shale (upper part)	

His correlation table is reproduced here, in part, as Table 2.

Other European workers substantiate this position of the Ostrau beds, one even including all of this series within the E zone, placing the lower Sattelflöz in the H zone.[19] Eberhard Wirth,[20] after a

for the Mississippian in North America. Therefore both Knopp and Wirth place the Ostrau lower in the Namurian than Pattiesky. The Waldenburg series of Lower Silesia represents only the lower part of the Ostrau, according to most reports.

The Chester-Morrow interval has been regarded as of comparatively short duration by most workers. In the type Chester areas around the southern margin

[18] "Das Verhältnis der Zonen von *Diplotema adiantoides* und der Lygnopteris Arten zu den Goniatiten-zonen des ostsüdetischen Karbons," *Compt. rend., Deuxième cong. avance. des ét. de stratigr. carbonifère, Heerlen, 1935*, pp. 719–20.

[19] L. Knopp, "Einige neue Goniatitenfunde im Oberschlesien," *Geol. Vereinigung Oberschlesiens, Jahresber., 1934* (1935), Pl. 2.

[20] "Die faunistische Altersbestimmung der Ostrau Schichten," *Neues Jahrb.*, Beilage-Band LXXIII, Abt. B (1915), Table 7.

of the Eastern Interior basin in Illinois and Kentucky, the oldest Pennsylvanian (probably as old as Morrow) rests on variable thicknesses of the Kinkaid limestone, but locally it overlaps Chester formations as low as Menard. On the east and southeast side of the basin in Kentucky and Indiana a number of channels, some 300 feet deep, have been cut into the Chester by pre-Pennsylvanian erosion.[21] At other places in the central United States the Pennsylvanian rests on successively older formations, down to the Ordovician St. Peter sandstone, a horizon stratigraphically about 5,000 feet below the base of the Pennsylvanian of southern Illinois. While this erosion was going on, deposition occurred in some parts of the continent. It is in these areas that the conclusive evidence of the age of the Stanley and Jackfork and other formations of uncertain affinities, such as the Parkwood of Alabama and the Tensus of Texas, will be found.

The greatest known thickness of Upper Mississippian rocks outside of the type Chester area is found in the Mauch Chunk and upper Greenbrier of southeastern West Virginia and adjoining parts of Virginia. In this area D. B. Reger[22] described an aggregate of almost 4,000 feet of Chester beds in the two series. Even if the Princeton and the Bluestone, which may eventually be shown to be a part of the Pocahontas group, are excluded, nearly 3,000 feet of beds remain in the Upper Mississippian. Recent ostracode studies have shown the fauna of the Reynolds member of the Bluefield formation to be about Menard in age.[23] If the Droop is correlated with the Palestine, there remain about 2,000 feet of beds which cannot reasonably be crowded into the Clore-Kinkaid interval of the type section. When the lower parts of the Chester–Mauch Chunk correlations are taken into consideration, the probabilities are that the several hundreds of feet of upper Mauch Chunk were deposited after Kinkaid deposition or during the post-Chester–pre-Pottsville interval, or the interval between the Pitkin and the Hale of Arkansas.

The middle Pottsville, according to Charles Butts,[24] is equivalent to the New River group of West Virginia and the upper Lee and lower Norton of Virginia. There are approximately 1,000 feet of beds in the lower Pottsville or Pocahontas group. The upper Chester, above the Wedington sandstone in Arkansas, contains about 700 feet of strata. If present correlations with southeastern West Virginia are correct, some 2,000 or more feet of strata lie above the middle Chester in the upper part of the Mauch Chunk series. Here, then, are some 3,000 feet of strata of post-middle Chester and pre-middle Pottsville age, which have no correlatives in the Pitkin-Hale unconformity and in which interval lie the Stanley and Jackfork formations.

CONCLUSIONS

The Pennsylvanian age designation of the Stanley shale and the Jackfork sandstone, on the basis of correlation with the Ostrau and Waldenburg series, classed as European Upper Carboniferous, and upon inadequate invertebrate data, deserves reconsideration because

[21] J. Marvin Weller and A. H. Sutton, "Mississippian Border of Eastern Interior Basin," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XXIV (1940), p. 848.

[22] David B. Reger, *W.Va. Geol. Surv. Rept., Mercer, Monroe, and Summers Counties* (1926), pp. 291–491.

[23] Chalmer L. Cooper, "Chester Ostracods in Illinois," *Ill. Geol. Surv. Rept. Inv. 77* (1941), p. 13.

[24] "Geology of the Appalachian Valley in Virginia," *Va. Geol. Surv. Bull. 52* (1940), p. 417.

of the information presented by European workers at the second Heerlen Congress and in other publications.

The Stanley and Jackfork formations deposited in a post-Chester–pre-Pottsville interval, although probably younger than any known Chester in the Mississippi Valley type area, are not necessarily Pennsylvanian in age. Whether these formations are Pennsylvanian, equivalent to some part of the 1,000 feet of Pocahontas lying below the Morrow horizon, or are Mississippian, correlative with some part of the 2,000 feet of beds younger than the type Chester, must await the presentation of more pertinent evidence from both the Appalachian and the Midcontinent areas. If correlative with the European E and H zones, which are probably equivalent to our Mississippian upper Chester and post-Chester formations, the Stanley and Jackfork should be considered Mississippian in age.

Considered on a diastrophic basis, the later stages of a period in a region of orogenic disturbance begin with preliminary pulsations which are reflected in the changing character of the formations toward the top of the system. The sediments become more clastic, finally resulting in coarse sandstone with beds of conglomerate. Such was the history of the closing stages of the Ordovician when, after early shale deposition, pulsations of the Taconic orogeny gave rise to the Bald Eagle conglomerate and the Juniata sandstone before the recognized close of the period.[25] Likewise the close of the Devonian was marked by the Acadian orogeny producing the thick Catskill clastics before its culmination. Somewhat similar conditions characterized the Laramide orogeny closing the Cretaceous period. The Stanley is predominantly shale and marks the beginning of the Wichita orogeny, while the Jackfork is predominantly sandstone, marking a later phase of the orogeny. The Morrow and Atoka, which are truly Pennsylvanian, were deposited in the earliest Pennsylvanian sea after the culmination of the Wichita orogeny.

[25] R. T. Chamberlin, "Pleistocene Coast Range Orogenesis in Southern California," *Jour. Geol.*, Vol. LII (1944), p. 358.

AN OCCURRENCE OF GRANITE IN POPE COUNTY, ILLINOIS[1]

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ABSTRACT

Fragments of weathered granite have been found in eastern Pope County, Illinois, in an area of widespread basic igneous intrusives. The origin of the fragments is a matter for conjecture. No parent granitic intrusive has been discovered, but neither has conclusive evidence of glacial origin been found.

INTRODUCTION

The first discovery of an igneous intrusion in Illinois was by W. S. Tangier Smith in 1902. This was the Mix dike of Pope County in the Ohio River bluff, 2 miles north of Golconda. During the course of subsequent field work in 1903 by members of the United States Geological Survey, igneous rock was found in outcrop at three other places, and two more localities were discovered where loose fragments of igneous material occurred. Specimens studied by Albert Johannsen were identified as mica-peridotites and lamprophyres.[2]

The presence of dikes of basic igneous rock intruding coal No. 5 in near-by Saline County was reported in 1907,[3] and more detailed descriptions of these dikes were published in 1919.[4] A sample from one of the mines at Eldorado was identified as olivine kersantite by Dr. Johannsen.

Field work in 1917–19 in preparation for the report on the geology of Hardin County[5] included a restudy of the known igneous occurrences, the discovery of the Sparks Hill intrusion, and the recording of another locality, previously found by U. S. Grant. L. W. Currier studied specimens of these rocks and, in addition to the types identified by Johannsen from that area, recognized the occurrence of "volcanic breccia(?)."[6]

Test borings for oil in 1940, some 3 miles southwest of Omaha, Gallatin County, encountered numerous dikes and possibly sills of mica-peridotite.[7] Outcrops of basic dikes are reported in the southeastern corner of Franklin County.[8]

Field studies beginning in 1941 and connected with wartime fluor spar investigations have resulted in the discovery, on the flanks of Hicks dome, of two new igneous-rock outcrops by R. M. Grogan. New developments by the Aluminum Ore Company have brought to light igneous rock recognized by A. H. Sutton in mine workings and diamond-drill cores in and near the Blue Diggings vein. "Mica dirt" is reported

[1] Published by permission of the chief of the Illinois State Geological Survey.

[2] H. F. Bain, "The Fluorspar Deposits of Southern Illinois," *U.S. Geol. Surv. Bull. 255* (1905), pp. 27–30.

[3] Frank W. De Wolf, "Coal Investigation in the Saline-Gallatin Field, Illinois, and Adjoining Area," *U.S. Geol. Surv. Bull. 316* (1907), p. 122 (reprinted in *Ill. State Geol. Surv. Bull. 8* [1907], p. 216); "Coal Investigations in Saline and Williamson Counties, Illinois," *Ill. State Geol. Surv. Bull. 8* (1907), p. 241.

[4] G. H. Cady, "Coal Resources of District V," *Ill. State Geol. Surv. Co-op. Min. Ser. Bull. 19* (1919), pp. 34–35, 56–61.

[5] Stuart Weller *et al.*, "The Geology of Hardin County," *Ill. State Geol. Surv. Bull. 41* (1920).

[6] *Ibid.*, p. 237.

[7] R. M. English and R. M. Grogan, "The Omaha Pool and Peridotite Intrusives, Gallatin County, Illinois" (in manuscript).

[8] Carl B. Anderson, Gulf Refining Company, personal communication, October, 1943.

to have been found in auger prospecting along the lower part of Grand Pierre Creek. Finally, weathered granitic fragments were observed by J. M. Weller about a mile southwest of the old Empire mine.

This last occurrence is of particular interest because it may indicate the presence of an igneous intrusion of quite different character from any other known in southern Illinois or the adjacent part of Kentucky.

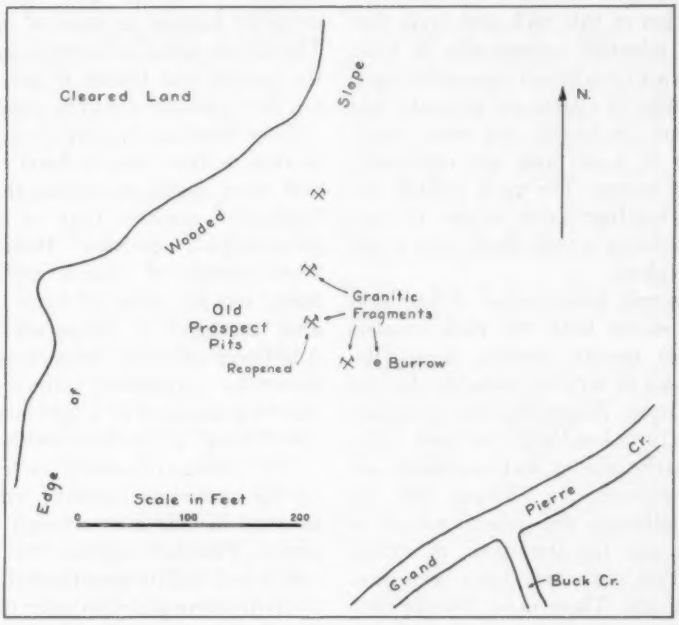

FIG. 1.—Sketch map showing location of granite in NE. ¼, SE. ¼, Sec. 33, T. 11 S., R. 7 E., Pope County.

POPE COUNTY GRANITE

Fragments of much-weathered, light-colored granitic rock and vein quartz containing flakes of muscovite were first seen on the dump of an old prospect pit (Fig. 1) located at an elevation of about 410 feet in the western part of the NE. ¼, SE. ¼, Sec. 33, T. 11 S., R. 7 E., Pope County. The prospect pit is halfway up the slope on the northwest side of Big Grand Pierre Creek nearly opposite the mouth of Buck Creek. Golconda shale and limestone underlie the slope, Cypress sandstone outcrops in the creek bed near by to the northeast, and Hardinsburg sandstone occurs up the hillside to the west.

The pit was later reopened to a depth of about 6 feet through the courtesy of Mr. Ira Adams, of Karber and Adams, at that time operators of the near-by Douglas fluor spar property. It exposed only talus material; but, in addition to the sandstone blocks and fragments of shale and weathered and silicified limestone, it also yielded fragments of granitic rock. The largest piece encountered

was about 1 foot in diameter. A search of the hillside produced several small fragments of similar rock, derived from other prospect pits, both higher and lower on the slope, and from a woodchuck burrow at the base of the hillside.

PETROGRAPHIC CHARACTER

R. M. Grogan has made a preliminary examination of this rock and finds that the only minerals recognizable in hand specimen are quartz and muscovite mica. The granules of quartz are generally less than 5 mm. in length, but some specimens up to 6 cm. long are essentially masses of quartz. The mica crystals are all small, less than 3 mm. across. In most hand specimens a rude linear flow structure is evident.

Microscopic examination of four thin sections shows that the rock consists mainly of quartz, biotite, muscovite, and masses of sericite probably derived from feldspar. Magnetite and secondary hematite form less than 1 per cent of the rock. Apatite, zircon, and tourmaline are rare accessories. No feldspar was observed, although the general nature of the rock and the abundance of sericite suggest that some may have been present originally. There is no definite indication of ferromagnesian minerals other than biotite.

Quartz makes up an estimated 55 per cent of the rock, biotite 10 per cent, muscovite 5 per cent, and sericite most of the remaining 30 per cent.

The quartz is in crystals mostly less than 1 mm. in size, containing numerous lines of tiny inclusions and showing prominent undulatory extinction. Commonly a number of these smaller crystals are interlocked with one another, producing the larger masses visible in hand specimens. The biotite is in laths ranging up to several millimeters in length and is so strongly bleached that only a faint pleochroism can be seen. The muscovite is in laths of similar size but of perfectly fresh appearance.

Most of the sericite is fibrous, many of the fibers being arranged in small fan-shaped aggregates; but occasional larger patches of sericite exhibit more or less uniform extinction and resemble imperfectly formed crystals of muscovite. The sericite areas lie between and around the quartz and biotite in places where primary feldspar would be expected.

Flow structure is more clearly evident in thin section than in hand specimens and more nearly resembles that of the "primary" gneisses than of the truly metamorphic gneisses. Biotite laths, linear groups of quartz crystals, and linear sericitic areas all have their long axes arranged in subparallel fashion. Additional effects of stress appear to be shown by undulatory extinction in the quartz grains and by slight bending and "stretching" of biotite crystals.

The common linearity is not shared by the muscovite, however, whose laths, as often as not, lie at strongly divergent angles. This fact suggests that the muscovite and sericite were formed, probably by hydrothermal action, after the crystallization of the quartz, biotite, and possible feldspar and after the development of the parallel texture.

The granite fragments might be weathered debris from a small dike or plug beneath the site where the fragments were found. Many such small intrusives exhibit flow structure of the type described above. The considerable range in grain size of the quartz is less characteristic of normal small intrusives but might be the result of the hydrothermal activity responsible for the unoriented muscovite and the sericite.

Additional evidence bearing on the

origin of the granite consists of the occurrence near the prospect pits of angular blocks of highly quartzitic sandstone. Some quartzitization of sandstone is commonly present along the faults in Pope and Hardin counties. No fault is known, however, close to this locality; and, moreover, the quartzitization of some of these blocks is more complete than is generally found along the known faults of the region. This suggests that some process other than faulting, perhaps contact metamorphism, may have produced the quartzite.

POSSIBLE GLACIAL ORIGIN

Because no actual exposure was discovered, the existence of a granitic intrusion at this place has not been established, and the alternative possibility that this material is of glacial derivation must be carefully considered.

A granitic boulder in Pope County might have reached its present location by ice-rafting during later Pleistocene time, when the lower Ohio River and its tributary valleys were ponded. Boulders, believed to have been transported in this way, were found by Stuart Weller near Carrsville, Kentucky, across the Ohio River from Rosiclare, Illinois.[9] The Pope County granite, however, occurs 7 miles north of the Ohio River and up to an elevation of about 430 feet. This is 100 feet higher than the present Ohio River, considerably higher than any of the late-Pleistocene terraces present in the region and higher than any ponded stage of the river that is known. The highest terrace recognizable near the mouth of Grand Pierre Creek has an elevation of between 340 and 360 feet. An ice-rafted boulder might have been carried to this position by a sudden rise in level of the Ohio, such as might be occasioned by the release of water ponded behind an ice-jam upstream. The Pope County granite, however, is deeply weathered, whereas known ice-rafted boulders consist of practically fresh rock or have weathered "rinds," $\frac{1}{2}$ inch thick at most.

Granite in Pope County might be part of an outwash deposit derived from a glacial ice lobe to the north. Grand Pierre Creek, however, heads several miles south of the margin of the Illinoian drift sheet, and neither it nor any nearby valley is known to carry outwash. Moreover, the granite occurs upon a hillside some 75 feet above the valley bottom and is more deeply weathered than would be expected of Illinoian outwash.

The most reasonable alternative to a local intrusion as the source of the Pope County granite appears to be a hitherto unrecognized remnant of ancient glacial drift located considerably south of the margin of the Illinoian sheet. A few such remnants have been recognized in southeastern Missouri, southern Illinois, and northern Kentucky.[10] These remnants are mostly located high topographically, in situations where they have escaped erosion. The Pope County granite occurs as fragments on the steep southeastern slope of a knob separated by a low saddle from, and about 20 feet lower than, the prominent ridge west of Grand Pierre Creek. Conceivably, this knob could bear a small remnant of ancient

[9] Frank Leverett, "The Pleistocene of Northern Kentucky," *Ky. Geol. Surv.*, ser. 6, Vol. XXXI (1929), pp. 37 and 43.

[10] Leverett, "Oldest (Nebraskan?) Drift in Western Illinois and Southeastern Missouri in Relation to 'Lafayette Gravel' and Drainage Development" (abstract), *Geol. Soc. Amer.*, Vol. XXXV (1924), p. 69; "Pleistocene Features in Ste. Genevieve County, Missouri," footnote in Geology of Ste. Genevieve County, Missouri, by Stuart Weller and Stuart St. Clair, *Mo. Bur. Geol. and Mines*, ser. 2, Vol. XXII (1928), p. 252; and pp. 33–35 of ftn. 9.

drift concealed by a thin cover of loess, and the weathered nature of the rock would be consistent with such an occurrence. However, a careful search of the dumps adjacent to the old prospect pits, the near-by hillside, and fresh gullies that drain away from the knob in the opposite direction has failed to reveal any other rock fragments that could not have been derived from formations naturally outcropping at this place. If a glacial remnant existed here, it would almost certainly include other erratic material in addition to granite, and other erratics should be found.

CONCLUSIONS

The origin of the Pope County granite has not been established. It cannot be definitely assigned to a local intrusive until the solid granitic parent-mass is exposed. On the other hand, its derivation from a near-by remnant of ancient glacial till is not substantiated by the finding of other associated erratic material.

FURTHER OBSERVATIONS ON THE ORIGIN OF BEACH CUSPS

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Since the publication of my article, "The Classification and Origin of Beach Cusps,"[1] I have examined scores of miles of shoreline. Although nothing has been found to change the conclusions as given in the first paper, some new relations have been discovered that seem worth recording.

Cusps of Class 1[2] were described as "very large capelike cusps formed during storms along beaches that are susceptible to considerable erosion and deposition." Such storm cusps result from the concentrated work of waves and currents, which causes rapid local erosion at the shoreline, resulting in overloading of the transporting agents, which are then forced to drop a part of their loads a short distance to leeward. The obstruction thus formed turns the shore current outward, and a cuspate form is built.

Such a cusp may remain isolated and unrelated to other cusps, or the waves may refract around its end and cause erosion to its leeward. Thus a second indentation is formed, the currents and waves are again overloaded, and another projection results.

Storm cusps, when first formed, have a short underwater extension at their outer ends, but as current action and beach drifting continue, a subaqueous ridge is sometimes built out for a long distance. This ridge may later be moved inshore by the waves of translation until its material again forms a part of the beach ridge.

Where there is a large amount of sand and the water is shallow with a gentle offshore slope, these cusps with their underwater extensions are nearly perpendicular to the shoreline, and the submerged ridges remain straight. Such shallow-water cusps constitute Class 2[3] and are described as "large cusps which have their apexes continuing out into the lake as a ridge of sand on the lake bottom." They are numerous along the west shore of Lake Huron. Some of these reach out into the lake a long distance and maintain their positions for years. They are also found along the shores of some of the inland lakes, such as Douglas Lake in northern Michigan and Silver Lake near Little Point Sable. That this type of cusp, with its underwater ridges, is built of material carried out from shore is shown by the changes that have occurred in Silver Lake. The level of Silver Lake changes slightly from year to year because of changes in its outlet. In those years when the water is low, it has a narrow sandy beach. Then cusps of Class 2 are always present. During the past summer, however, the water covered the sand, the vegetation along the shore prevented all beach drifting, and no cusps were formed.

Class 4[4] are "very small cusps formed at the lower ends of grooves which are sometimes formed just above the waterline and are perpendicular to it." These are always very small and never develop into cusps of a larger size. They are really a series of rill marks and, considering

[1] *Jour. Geol.*, Vol. XLVI (1938), pp. 615–27.

[2] *Ibid.*

[3] *Ibid.*

[4] *Ibid.*

their origin, probably should not be classed with beach cusps. However, since at the bottom of the channels are small cusplike deposits and since they have also been described as cusps by D. W. Johnson,[5] they should probably be retained in the classification.

Regarding Class 5 cusps,[6] which always occur in a series, long study and observation have convinced me that they never form except through the process of breaking of a ridgelike obstruction by the waves. This ridge is usually a beach ridge, but it is sometimes merely the edge of a low-cut bank. It is not necessary for a reverse slope to be present. All that is necessary is that the waves have an opportunity to cut through a long obstruction parallel to the shoreline. In the examination of hundreds of such series of cusps, I have found no exception to this. Also I have never seen a cusp series formed where the beach sloping toward the water was backed by an elevation too high for the waves to go over it.

The following example is typical of many beaches examined. On July 2, 1943, at Gray's Landing on Lake Michigan, about three miles north of White Lake Harbor, there were three series of cusps, each about 200 feet long, separated by equal distances of smooth beach. The waves had cut into the foredunes and caused the formation of a sand cliff several feet high. Where the cliff was close to the shore, the waves had built a smooth sloping surface which graded gently into the face of the cliff. Here no cusps formed, but in every case where the cliff retreated from the shore some distance, beach ridges, broken by cusp series, were present.

[5] *Shore Processes and Shoreline Development* (New York: John Wiley & Sons, Inc., 1919), pp. 475–76.

[6] Pp. 615–27 of ftn. 1 (1938).

RECENT STUDIES OF HALIBURTON-BANCROFT ALKALINE ROCKS: A DISCUSSION

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This note is inspired by the recent publication of a geological map, by W. K. Gummer and S. V. Burr, of the area immediately east of Bancroft, Ontario.[1] The area shown on this map is the central part of a somewhat larger area that I had previously mapped and described.[2] The Gummer-Burr map is characterized by considerably less extrapolation than mine; and its location of specific outcrops or quarries is in general to be preferred, though there is, for the most part, little difference between the two maps.

Where the origin of rocks is so questionable, it seems very poor practice to introduce genetic nomenclature. Although the shonkinites and many of the syenites are probably "paragneisses," the use of the term as a map unit gives no indication of their peculiar mineralogical relation to the granites and nepheline rocks. (Most of the rocks I described as "potash-soda syenite-shonkinites" were collected from outcrops mapped as "paragneiss" by Gummer and Burr.) But this is a very minor matter; and all parties would be placated, I think, by the use of a composite term such as "syenitic-paragneiss" or "saturated-paragneiss." Despite the lack of significant difference between our maps, we are in almost complete disagreement concerning the origin of the alkaline rocks.

As far as field observation is concerned, the only significant difference between the earlier work of M. L. Keith,[3] my own study,[2] and the subsequent ones of Gummer and Burr,[4] J. Satterly,[5] and J. Thomson,[6] seems to me one of emphasis rather than of fact, hinging on the existence and importance of oversaturated or saturated rocks younger than the strongly undersaturated types. Although the common microperthitic syenites and shonkinites seemed to me to predate the nepheline rocks, I stated clearly that the plagioclase syenites were probably contemporaneous with them. The syenitic streaks which often cut across the foliation of gneissic foyaites I considered to have been derived by the reaction of liquid granite-pegmatite on solid nepheline rocks—a reaction for which the field offers considerable evidence. If these syenitic streaks are not of syntectic origin, then a certain amount of syenitic liquor must have remained liquid after the solidification of the nepheline rocks. Except for these rather insignificant streaks, I found no good evidence for such syenite; but Satterly has provided descriptions and an excellent photograph of outcrops in which gray syenite (the "plagioclase syenite" of my paper?) appears to carry inclu-

[1] *Ont. Dept. Mines Ann. Rept.*, Vol. LII (1943), accompanying report of J. Thomson.

[2] *Bull. Geol. Soc. Amer.*, Vol. LIII (1942), p. 452.

[3] *Bull. Geol. Soc. Amer.*, Vol. L (1939), p. 1795.

[4] *Science*, Vol. XCVII, No. 2517 (1943), p. 286.

[5] *Ont. Dept. Mines Ann. Rept.*, Vol. LII (1943), Part II, p. 13.

[6] *Ont. Dept. Mines Ann. Rept.*, Vol. LII (1943), Part III, p. 9.

sions of gneissic foyaite. Although there are numerous local developments of acid pegmatites younger than the nepheline rock, the results of my study were equally disappointing with regard to the existence of any considerable amount of younger granite. The intrusion of vast quantities of younger (but not necessarily related) granite is highly probable, but the few outcrops of massive granite I found gave no clear evidence of age relations. Since the massive granite is uncrushed, it could have appeared during or after deformation and hence could have accompanied or succeeded the nepheline rocks; the latter is surely more probable than the former.

But nearly all the granite of the area is gneissic, and most of both granite and the common microperthitic syenite shows evidence of mild deformation. In places the syenite has been thoroughly milled, and in the shonkinites evidence of deformation of the dark minerals is sometimes preserved despite their usually thorough recrystallization. Both gneissic granite and massive syenite are common as inclusions in the flow marble. In contrast, nepheline rocks have not yet been found as inclusions in the marble: nepheline in the nepheline pegmatites and injection gneisses shows evidence of neither "wet" nor "dry" metamorphism, and, concerning the massive foyaite of Blue Mountain, Keith[7] concludes that "there are no cataclastic structures or other microscopic evidence of movement or deformation during crystallization." Save for some of the acid pegmatites, no one has yet shown conclusively that any of the igneous rocks of the area are younger than the nepheline pegmatites which are the dominant undersaturated rocks of the eastern portion of the field; and it is my suspicion that such a demonstration is impossible. The issue between me and other recent students of the area thus resolves itself into (*a*) a question of fact, as to whether or not significant quantities of syenite and granite can be shown to be younger than the moderately undersaturated rocks; and (*b*) a matter of opinion, as to what importance should be attached to such a relationship. With regard to the question of fact small amounts of syenite seem to be younger than foyaite; and large quantities of granite *might* be younger, but my own evidence permits this inference only for scattered, isolated outcrops. What, then, of the second point?

The complexity of the Haliburton-Bancroft field is well known. From north to south there is a well-established transition from an area of igneous activity through a broad contact zone into a region of comparatively unaltered sediments. From west to east there seems to be a transition from truly plutonic igneous activity, as exemplified by Blue Mountain, to very late pegmatitic action, as shown so remarkably along the York River east of Bancroft. The plutonic nepheline rocks are foyaitic in composition; the pegmatitic ones, much more nearly urtitic. Except at Blue Mountain, very little of the magma crystallized *in situ*.

In a region as large and complex as this, it is certainly folly to base fundamental conclusions or objections either on the assumption that the magma composition varied uniformly in time throughout the field or on the parallel assumption that liquids of identical composition would crystallize simultaneously in different portions of the field. Both of these conclusions are necessary if the limestone-syntexis hypothesis is to

[7] P. 1824 of ftn. 3.

be rejected chiefly because occasional saturated or oversaturated rocks are shown or inferred to be younger than moderately undersaturated rocks. This seems the major premise of the argument of Keith, Thomson, and Satterly. It is to be expected that rock sequences will be contradictory with regard to intermediate members of the series, and it is surprising that the end members do not show similar relations.

A little syenite or granite later than massive or gneissic foyaites will not disprove the limestone-syntexis hypothesis any more than a little early syenite will prove it. But evidence suggesting that, in general, the oversaturated and saturated rocks are older than the strongly undersaturated rocks greatly increases the plausibility of the hypothesis; and evidence that some of the syenite, as well as scattered outcrops of massive granite, are or may be younger than the moderately undersaturated rocks will not seriously disturb this conclusion.

So much, then, for the differences of fact or emphasis between my work and that of Gummer, Burr, Thomson, and Satterly. Since my own work and that of Gummer and Burr were done in precisely the same area and we seem to conflict in matters of fact only to the extent already discussed, it will not be amiss to state my position concerning their theoretical conclusions.

That the nepheline pegmatites "may have . . . . been released by reactions of granitic or syenitic juices on limestone" seems plausible to me, but that "many of the nepheline pegmatites appear to be the result of regeneration of the nepheline of the paragneisses" seems to me without foundation. Rather, I suspect that its foundation is probably a study of many of the same outcrops from which I concluded the pegmatites were the source of the nepheline now found in the gneisses.

My own conception of the emplacement of nepheline[8] was simple and perhaps unimaginative: into the previously solid paragneisses a thin pegmatitic fluid of about urtitic composition was introduced. Where open cracks were available, they were filled (and perhaps greatly widened) by the liquid, which crystallized as nepheline pegmatite. Where the country rock did not fail by large-scale rupture, it was subjected to an extensive *lit-par-lit* injection of pegmatite liquids, the final product being a series of urtite-paragneiss hybrids.

Although this process might have been called "nephelinization" or "granitization," I felt that these terms could neither add to nor substitute for a more complete description and were therefore without any particular utility. The regeneration favored by Gummer and Burr is almost the exact converse of my explanation; yet the words "nephelinization" and "granitization" are as justly used by them as they might have been by me. What do we accomplish by such nomenclature?

Where contact planes are parallel to the structure of the wall rocks, most outcrops containing nepheline pegmatite and syenite, shonkinite, or foyaite are probably not incompatible with either hypothesis. There are localities in the eastern portion of the field, however, in which the interpretation of nepheline as anything but a late pegmatitic injection would scarcely be admissible. One of the best of these is the Snow Road Valley in the northeastern part of the town of Bancroft. The "regenerationist" may, of course, reply that nepheline injected into

[8] P. 503 of ftn. 2.

paragneiss at one locality has been derived *from* paragneiss elsewhere, but this sort of argument can be continued indefinitely.

It is one of the very great dangers of most "ultra-metamorphic" hypotheses that they cannot be definitely disproved. In this case, for instance, the mere fact that there is no presently recorded evidence for regeneration may be taken by some as an indication that regeneration has been so thorough as to destroy relations characteristic of initial and intermediate stages of the process. The only possible resolution of the controversy—one which is almost dictated by the overbroad terms in which it is necessary to state most "ultra-metamorphic" concepts—rests in the discovery of outcrops in which the distribution of nepheline can be explained only by its regeneration from paragneiss. Perhaps the brevity of the Gummer-Burr paper prevented inclusion of critical positive evidence of this type; it is to be hoped that the omission will be repaired. In any case, it is idle to speculate about the relative importance of regeneration as opposed to the more conventional *lit-par-lit* injection of liquid magmatic material before the presentation of at least a little field evidence in favor of the new suggestion.

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REVIEWS

Foundations of Plant Geography. By STANLEY A. CAIN. New York: Harper & Bros., 1944. Pp. xiv+556; figs. 63. $5.00.

The scope of a scientific field increases so rapidly that it is next to impossible for an individual worker to maintain a proper perspective not only of his own field but also of all related fields. Therefore, we are greatly indebted to the author for the completion of a herculean task: the assembly of a large amount of material, in what he chooses to call *The Foundations of Plant Geography*, and its analysis and evaluation. Analyses of groups of related titles are in many cases deeply penetrating. The conservative nature of the evaluation accomplishes two things: it leaves the reader with a desire for more extended evaluation, difficult as the task may be, and it creates an urgent stimulus to further investigation by the clean-cut delineation of a myriad of problems.

In addition to the text, Dr. Cain's book contains a glossary of uncommon terms, a literature-cited section of 720 titles, and a rather complete index. The text contains thirty chapters divided into five parts as follows: "Introduction," "Paleoecology," "Areography," "Evolution and Plant Geography," and "Significance of Polyploidy in Plant Geography." By no means does the book conform to the ordinary idea of descriptive plant geography. If one desires a simple answer to the problem, "Why plants are where they are and how they got there," he will be disappointed. The book, rather, is a critical review of a large mass of literature excellently organized. Although the temptation exists to question the absence of certain titles from the Bibliography, a single book is necessarily restricted to the objectives of the author, and it is obviously impossible to include all work considered pertinent to plant geography by all workers. In the opinion of the reviewer, Dr. Cain has performed a highly valuable service, one which might well be emulated in other fields from time to time.

The text material dwells heavily upon paleoecology, dispersal, speciation, and polyploidy. Throughout its entirety the central theme appears to be evolution, and this viewpoint binds together contributions from paleobotany, taxonomy, genetics, cytology, dynamic plant distribution, and the causes of speciation. As a matter of fact, an additional background of plant physiology, plant anatomy, paleobotany, physiography, climatology, meteorology, and pedology is a great help for the full appreciation of Dr. Cain's review. The whole work illustrates clearly how progress in a single field of investigation depends upon and is assisted by contributions from many fields.

Some readers might take exception to the title of "Foundations" or even of "Principles." However, the principles of plant geography constitute the entire theme of chapter ii and are emphasized from point to point in Part II, "Paleoecology." The principles are well summarized with good argument and pertinent examples except, perhaps, in the case of optimum and limiting factors, which are rather involved topics for the restricted consideration given them.

Because of the manner of treatment, geologists and paleobotanists are most likely to be interested in the large section devoted to paleoecology, including chapters on "The History of Cenozoic Vegetation of Western America" and "Pollen Analysis as a Paleoecological Research Method." Emphasis is placed upon principles, methods, and examples from recent work, especially from the penetrative and comprehensive work of Chaney. In spite of a slight perplexity in the author's mind as to the balance between divergent interpretations, his critical analyses are straightforward and lucid. One wishes he had been able to go even further in the selection of salient features of various schools of thought and their evaluation. The extensive work of Chaney and his students, of Mason, Berry, and others, merits an analysis and evaluation beyond the space permissible in the present book. In any event, if a person wishes to be sufficiently well grounded in the principles of paleoecology and their application, he must necessarily digest the details in the original articles. The brevity of the one chapter on pollen analysis, although a myriad titles are concisely interwoven, is no doubt justified in the light of the excellent books already in existence.

The remainder of the book tends increasingly toward an evolutionary approach. At times the connection with plant geography becomes tenuous or even appears to be lost sight of altogether. This is especially true of such topics as the nature of species, speciation, species stability, and polyploidy. The diverse topics could, perhaps, have been more intimately interwoven—a most difficult task. However, the reader perceives a future value of high order to plant geography in research suggested by Dr. Cain's treatment. A wealth of well-co-ordinated information, especially in the topics of area, dispersal, centers of origin, endemism, senescence, and isolation, yields a broad perspective not only for those who work in related fields but also for those directly concerned with the topics. This, of course, is quite true for the entire book.

On the whole, we are indebted to Dr. Cain for accomplishing three things: first, he has assembled, reviewed, and evaluated a large amount of the recent literature pertinent to plant geography or related in some way thereto; second, he has focused attention once again upon the essential unity among several branches of science; and, third, he has in numerous cases highlighted the many problems awaiting investigation.

WALDO S. GLOCK

Foreign Maps. By EVERETT C. OLSON and AGNES WHITMARSH. New York: Harper & Bros., 1944. Pp. xvii+237; figs. 25; tables 7; pls. 16. $4.00.

The present conflict is a war of maps as well as of ships, tanks, and planes. Soldier and civilian alike have become involved, it seems at times almost submerged, in the flood of maps flowing, no longer by hundreds and thousands, but by tons and carloads. Numerous manuals and other books have appeared as aids to instruction in the making and reading of a great variety of maps. *Foreign Maps* is the latest of these and is almost the only volume in English which, for some forty countries, presents a brief but comprehensive treatment of their medium- and large-scale topographic maps. It is to be hoped that in the second edition large maps on a scale approximating an inch to a mile, which together might be considered a master-map of the world, will be treated more fully.

The primary organization of the book is topical, with chapters on signs and symbols, scales and measurement, marginal information, map indexes, and grid systems. Its unique features are proposals on procedure in reading foreign maps, an analysis of the characteristics of maps issued by national mapping agencies, and an extensive treatment of the difficult problem of language.

More than eighty pages are devoted to the translation into English of map vocabulary from Chinese, Japanese, German, Russian, Turkish, even Tibetan, and thirty other languages. The principal barrier to the use of foreign maps has been breached successfully.

Sixteen samples of foreign maps, half of them in color, are included in the volume. They are well chosen to illustrate various types of treatment, though clarity has in some cases suffered in reproduction. An arrangement whereby more or all of the maps could be seen at one time, addition of marginal data, and retention of original scales would improve their usefulness.

Foreign Maps is a timely and original description and analysis of the medium- and large-scale series of maps issued by most of the national mapping agencies of the world.

H. M. LEPPARD

The Structural Control of Ore Deposition in Some South Australian Copper Fields. By S. B. DICKINSON. Department of Mines, Geological Survey of South Australia, Bulls. 20 (1942) and 21 (1944). Pp. 99; figs. 29; and pp. 66; figs. 14.

Part I of Bulletin 20 deals with the Wallaroo-Moonta field, which, since its discovery in 1860, has been the most productive copper-mining field of South Australia, yielding copper ore roughly estimated at six and a quarter million tons. Large-scale mining ceased in 1923 and the mines are now completely dismantled. The only previous geologic report on the district is that of Dr. R. L. Jack, general in scope and published in 1917. The present report is restricted to the structural geology and is based wholly on the examination of mine maps and other office records, since direct underground examinations were impossible and surface studies were useless because a blanket of post-mineral formations completely masks the ore-bearing horizons. It is hoped that the present structural studies will offer aid and encouragement to further exploration for ores.

The ore deposits were formed in pre-Cambrian times and are hypothermal vein deposits traversing pre-Cambrian acid igneous rocks and metamorphosed sediments. In the Moonta district the ores occur in porphyry along two sets of thrust faults striking northeast and southwest and dipping to the northwest. The two sets diverge about 15° in strike. An unusual technique in some of the stope maps is the representation of the workable widths of certain ore bodies by contour lines. This brings out very well the pipelike forms of some ore bodies and the tabular form of others.

Cross-faults intersecting the principal veins are some of them pre-mineral and some post-mineral. The former have influenced mineralization by blocking mineralizing solutions, and the latter have displaced pre-existing ore bodies.

In the Wallaroo district 9 miles to the north, the ores occur in pre-Cambrian sedimentary and metamorphic rocks of whose rock structure nothing is known. Unlike the Moonta district, the ore bodies lie in steeply dipping east-west faults and have been sliced and mildly displaced by northeast-southwest shear zones. The latter trend similarly to the principal veins of the Moonta district, with which they may be contemporary, but they do not contain workable ore bodies. The author relates the fracture pattern in both the Moonta and the Wallaroo districts to various elements of the same strain ellipsoid.

Part II on the Dome Rock Copper Mine is a complete geologic study of an active copper mine characterized by small but interesting ore deposits. The mine lies 26 miles north of Mingary siding. The area consists of metamorphosed sandstones, shales, and ferruginous sandstones intruded by granite. Although the mine workings are within a few hundred feet of the border of the granite batholith, the minerals indicate mesothermal conditions of deposition. The sediments are lithologically similar to those at Broken Hill and have usually been regarded as pre-Cambrian. The age of the granite is unknown.

The two principal ore deposits are of especial interest because they are small pencil-like, steep-pitching patches of ore localized in minor drag-fold structures on the overturned limb of a strong anticline. To a depth of 200 feet the ores are oxidized. The primary ore consists chiefly of pyrite and chalcopyrite, which replace the country rock, usually a fine-grained sandstone.

Part III describes copper deposits of the "Red Beds" type found in the Mountain Gunson–Pernatty lagoon district. These deposits are localized within a distinctive flat-lying bed of dolomitic limestone and in conformable red sandstones immediately above or below. The cupriferous sediments are nonfossiliferous and appear to be terrestrial. They have been variously classed as Ordovician and as pre-Cambrian. The principal commercial deposits are at the Mount-Gunson mine, from which the ores are shipped to the Port Pirie smelters. Their high silica content gives them fluxing value in the smelting of less siliceous ores. In a few localities sulphides are present, chalcocite, covellite, and bornite; but most of the ores are oxidized. The irregular distribution of the mineralization within the sediments indicates an epigenetic origin. Conclusive evidence is lacking as to whether the mineralizing solutions were meteoric or magmatic (hydrothermal) in source. The reviewer cannot agree with the statement that the presence of barite and fluorite in some of the ores indicates that the ore solutions were hot rather than cold. There is ample evidence that both minerals may be deposited from cool meteoric waters as well as from thermal waters.

Part IV deals with the Burra Burra mine about 100 miles north of Adelaide. The mine was discovered about 1851 and worked for 26 years, yielding copper to the value of nearly five million pounds sterling. The rocks of the area consist of a conformable series of folded and mildly metamorphosed sediments that are without fossils and usually classed as pre-Cambrian. A single feldspar-porphyry dike intrudes these sediments.

The Burra Burra ore body was about 800 feet long and 250 feet in maximum width. Below a superficial leached zone the ore body extended to depths of only 300 feet. It was, however, very rich, running from 20 to 30 per cent copper for the dressed ore. All the commercial ore consisted of oxidized copper minerals and some chalcocite, but exploration by drilling has shown the existence below of pyrite and chalcopyrite in scattered distribution and not of commercial grade.

The ore resulted from processes of oxidation and downward enrichment acting on a pyrite-chalcopyrite protore above and near the groundwater level in an area of dolomites and calcareous shales shattered by faulting.

Parts V–IX relate to copper-producing dis-

tricts of lesser importance. They are of historic and local interest mainly.

EDSON S. BASTIN

Asia's Lands and Peoples: A Geography of One-third the Earth and Two-thirds Its People. By GEORGE B. CRESSEY. New York: McGraw-Hill Book Co., Inc., 1944. Pp. xi+608. $4.50.

This well-timed text is the first on Asiatic geography to present the continent in something like the perspective it should have in the middle of the twentieth century. Dr. Cressey has been in a peculiarly favorable position to bring the picture into better balance than has been done before, first by protracted residence in China and then by his unique good fortune in serving as adviser to the government of the U.S.S.R. during the preparation of the *Great Soviet World Atlas* (1938–40), material for which was inspected by delegates to the International Geological Congress at Moscow in July, 1937. In the ensuing months he had access to a wealth of new data and a variety of experiences which any geographer might envy. The result is the 120 pages in the heart of the volume which form its outstanding contribution.

The book is replete with factual material, much of which has not yet found its way into standard texts. Cressey's section on the natural resources of the U.S.S.R. is based on the figures for 1940. His Japanese estimates are as up to date, if not necessarily equally reliable.

The plan of the book is sound and well balanced. It abandons the classical line of attack from the western flank and approaches from the southeast, after a preliminary briefing in Hawaii on the geostrategy of the Pacific Basin. The division of the continent into major realms essentially follows Bergsmark's of 1935. Descriptions of each region start with a general picture of the area, followed by a sketch of the physiographic, climatic, and pedological foundations, upon which thereafter the distribution of vegetation, agriculture, and social life develop naturally. Good sentence-summaries of significant geological structures appear where germane to the discussion of land-forms and natural resources. Pertinent historical background is introduced in various places, though not always with full appreciation of the factors involved. Thus, while it is true that in early historic times the frontier of Japanese expansion stood for long on the shores of Lake Biwa, it should surely be added that just across the lake lay the real barrier, the tough rampart of the Central Mountain Knot.

The style is readable, often vivid, at times with arrestingly epigrammatic turns of phrase. Of the Soviet realm, "too much of the land is too cold, or too dry, or too wet . . . . or too something else. . . . . It has the longest coastline of any country, and the most useless. . . . . Even the rivers flow in the wrong direction." But the reviewer deprecates such verbal plastic surgery as the excision of prepositions from the subtitle of the book; even quotation marks would hardly atone for this journalese liberty!

The book strikes a fresh note in another respect. No study of the adjustment of man to his environment can afford to leave out of account racial psychological factors, especially where these influence national aspirations toward expansion. This is peculiarly true of Japan, where failure to allow for this driving force behind the people of the island empire led to their being seriously underestimated as a potential foe. (In this connection the map showing the progressive extension of Japanese hegemony is instructive to others besides students of history.) The chapter on "Japan's World Position" brings this whole aspect into proper focus, even though it is surprising to find no reference to the counterbalancing psychological "tug of the homeland," which has prevented the race from making good colonists and has limited the energies of the overseas Japanese on the Asiatic mainland to exploiting the localities in which they sojourned in hope of an early return to the islands of their birth.

It is to be regretted that, with so much to commend it, the publication shows so many signs of hasty preparation. Even with the plan, stated in the Preface, of confining to certain chapters the high lights of the major political units and relegating factual details to other sections of the book intended for more advanced students, the impression is left that the author never quite decided whether he was writing a textbook or a reference book. There is an alternation between excellent descriptive passages and masses of almost ponderous detail which must be studied with an atlas to derive their real value.

Nor are different sections of the book always thoroughly co-ordinated. Little is gained by introducing two independent classifications of the physiographic provinces of the same region, and

the result can only be confusing to the student. Thus the map on pages 270–71 shows "Landforms of the Soviet Union," devoid of the key-letters which would link them instantly with the systematic listing on the previous page; while pages 312–13 present "Geographic Regions and Geomorphic Realms" of the same area, indexed by a different letter-system and with different boundaries, yet with no attempt to reconcile apparent discrepancies. Two different climatic classifications of Japan appear on the same page. Similarly, the physiographic regions of Tibet are grouped differently on pages 55 and 156, with no explicit correlation between the nine numbered regions and the seven lettered ones of the same area and with a misplaced mountain range flanking the Karakorum. In other cases glaring errors must be due to slipshod editing—as where, among "India's Varied Flora," the astonished reader finds "tidal forests" mapped along the crest of the Himalayas and "dry alpine vegetation" along the Karachi coast. The "cyprus" trees, "Twai" River of China, and the like are evidently compositor's novelties.

The illustrations are, for the most part, culled from fresh sources and include a number of good air-photos, though the halftones fail to do them justice. All the diagrams and charts were specially drafted, but here, too, inadequate supervision of the work mars the result. A binding hardly robust enough for the heavily weighted paper may be a wartime necessity; but the value of diagram maps need not have been sacrificed by the use of confusing or indistinct conventional shading, unbalanced weight of boundary lines and lettering, or the absence of reference points on distribution maps. The three-dimensional effect of Raisz's characteristically beautiful Harvard-Yenching Physiographic Diagrams is largely killed by the superposition of crudely drawn boundaries. This is partly due to overreduction of the originals, a defect seen also in the blank areal maps, large margins of which might have been cropped as an alternative to excessive condensation of the significant region. While in comparing different regions there is obvious advantage in a uniform scale, that purpose could be achieved by a key-map on 1/30,000,000 at the entry to each new region, after which the scale of distribution-maps could be determined by the nature of the detail to be exhibited. Thus the map of land-forms of the Japanese island chain could be reproduced on a much larger scale by "insetting" the extreme northern outposts and Formosa, instead of including blank expanses of all Manchuria, southeastern Siberia, and 500,000 square miles of China and Mongolia, so that a lens is needed to distinguish the two symbols which alone justify the inclusion of the map. No key is given for the most prominent symbol (*SB*) on the map of China's raw materials, and the student must wait until the next chapter before guessing that it means "soybean."

Mention of such defects may seem petty; but where the aim of a book is to throw a fresh image on the mental screen, details of projection become important. It is only because these details can be readily corrected in a second edition that it is worth pointing them out. In a book of less genuine merit they could pass without comment.

A useful addition is the extensive annotated Bibliography which lists with discrimination all the more important publications in English up to 1943, as well as a number of standard ones in other languages. A valuable inclusion is the reference to available maps of the various regions; and instructors will note with appreciation that lantern slides of the photographic illustrations are securable from the Syracuse University bookstore.

GEORGE B. BARBOUR

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